

SUPPLEMENTARY DATA S1. Part A. Annotated descriptive list of the ontogenetic characters and their states used to recover the ontogeny of *Tyrannosaurus rex*.

Throughout the descriptions, the numerical codes of 0 and 1 are informally referred to as “juvenile” and “adult,” respectively, with the intent of expressing relative (not chronological) maturity. The subadult specimen CMNH 7541 was drawn upon as the primary exemplar of the juvenile condition for the skull and mandibular ramus, whereas BMRP 2002.4.1 was the primary exemplar of the juvenile condition for the postcranial skeleton. The type specimen of *T. rex*, CM 9380, was used as the primary exemplar of the adult condition; where bones are missing from that specimen, the adult specimens AMNH FARB 5027, FMNH PR2081, MOR 555, MOR 1125, and RSM 2523.8 were sought as primary exemplars. The actual exemplars used are listed with each character description.

In order to align the ontogenetic characters described here with the corresponding phylogenetic characters from Carr et al. (2017), and other relevant works (e.g., Rauhut, 2003; Carrano et al., 2012), the list begins with the phylogenetic characters that could be coded ontogenetically. A note on each phylogenetic character follows the summary of exemplar specimens that describes the alterations made to ontogenetic characters whenever they differ from their phylogenetic homologue.

Characters that are drawn from the phylogenetic literature are organized by three primary sources, which are cited at the end of each character description. In cases where a given character has appeared elsewhere in the literature, the source is cited in a note that follows the character description. Since the order of ontogenetic characters is not organized by the literature, Carr (1999) and Carr and Williamson (2004) are both cited in the character descriptions of ontogenetic characters.

PHYLOGENETIC CHARACTERS (CARR ET AL., 2017)

General Features (2 characters)

1. Body, size A (Carr et al., 2017: character 1): the skull, femur, or ilium is less than 572 mm long (0); from 573 mm to 739 mm in length (1); 740 mm in length (2); greater than 740 mm in length (3).

Exemplars: CMNH 7541 (0); n/a, the range between CMNH 7541 and BMRP 2002.4.1 (1); BMRP 2002.4.1 (2), LACM 23844 (3).

Note: The purpose of this character is to align the ontogenetic increase in size with the phylogenetic increase in size. The estimate of body size is extended to include specimens that are clearly smaller or larger than the exemplar specimens. For example an isolated frontal bone (DDM 344.1), which is approximately the same length as those of CMNH 7541, was coded with the juvenile condition. Specimens that are significantly larger than BMRP 2002.4.1 (which has a skull length of 740 mm), such as RSM 2990.1, are coded as having the adult condition. Ergo, specimens that are represented by few or single bones, that are significantly smaller or larger than BMRP 2002.4.1, are coded accordingly.

Phylogeny: Character 1 of Carr et al. (2017), without alteration; the ontogenetic juvenile condition corresponds to the phylogenetic small size of basal tyrannosauroids, whereas the ontogenetic adult condition corresponds to the phylogenetic level of derived tyrannosauroids, from *Dryptosaurus* to *T. rex*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from small to large.

2. Body, size B (Carr et al., 2017: character 1): the skull, femur, or ilium is 1.2 m (0); 1.3 m or greater (1).

Exemplars: MOR 1125 (0), LACM 23844 (1).

Note: The purpose of this character is to restore the size differences between specimens in the “greater than 740 mm” category from character 1. No distinction is made between skulls and femora that are 1.3 or 1.4 m in length, since either length of those structures are often seen in combination in individual specimens. Therefore, a distinction between a specimen that has a 1.3 m skull and a 1.4 m femur is not made from another with a 1.4 m skull and a 1.3 m femur.

Phylogeny: Character 1 of Carr et al. (2017) without alteration, aside from the focus on the extreme end of the size spectrum. Following Brazeau (2011), specimens with skulls and femora that are less than 1.2 m are coded as missing to avoid redundant duplication of character 1.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from small to large.

General Skull Features (1 character)

3. Skull, general shape, lateral view (Carr et al., 2017: character 3): long and low, length to height ratio greater than 3.1 (0); deep, length to height ratio equal to or less than 3.1 (1).

Note: The *length* is premaxilla to quadrate condyle length and *height* is the maximum height through the postorbital bar. The ratio for the subadult CMNH 7541 is 3.0, which is artificially low in view of the damaged and foreshortened temporal region. The ratio for the subadult BMRP 2002.4.1 is 3.8. The ratio in adults AMNH FARB 5027, FMNH PR2081, UWBM 99000 is 3.1, 2.3, and 2.6, respectively.

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 3 of Carr et al. (2017), where the threshold value is changed from 3.2 to 3.1 to reflect what is seen in adult *T. rex*. The ontogenetic long and low condition corresponds to the phylogenetic nontyrannosaurid condition, whereas the ontogenetic deep condition corresponds to what is seen in Tyrannosauridae, with the exception of the *Alioramus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to tall.

Orbital Fenestra (2 characters)

4. Orbital fenestra, shape, lateral view (Carr et al., 2017: character 7): large and round, with a length to height ratio of ~80% (0); tall, with a length to height ratio of ~70% (1); extremely tall, more than twice as tall as long (2). **ORDERED**

Note: In cases where the lacrimal is absent, the presence of a wide subocular process was used as a proxy for the adult condition; i.e., state 2.

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

Phylogeny: Variant of character 7 of Carr et al. (2017), where the intermediate state (“10% taller dorsoventrally than long rostrocaudally, but less than twice as tall as long”) was changed to correspond to the differences in the length to height ratios seen in the available subadults (CMNH 7541, BMRP 2002.4.1) that culminate in the extreme condition of adults. The ontogenetic juvenile condition corresponds to the phylogenetic basal tyrannosauroid condition, the intermediate ontogenetic condition corresponds to the derived tyrannosauroid (*Bistahieversor*

+ Tyrannosauridae) condition, and the ontogenetic adult state corresponds to what is seen in the clade *Tyrannosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from round to tall.

5. Orbital fenestra, orientation, dorsal view (Carr et al., 2017: character 9): face more laterally than rostrally (0), face slightly more rostrally than laterally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 9 of Carr et al. (2017); since the orientation of the orbital fenestra is difficult to measure, a qualitative version of the character is given here. The ontogenetic juvenile condition corresponds to the phylogenetic state seen from basal Tyrannosauoidea to derived Tyrannosaurinae, whereas the ontogenetic adult state corresponds to the phylogenetic condition of the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from lateral to rostral.

Premaxilla (6 characters)

6. Premaxilla, nasal process, tip, apposition between complementary bones, presence, dorsal view (Carr et al., 2017: character 11): in apposition (0); divergent, where the tips are separated by the nasals and they diverge from each other (1).

Note: This feature can also be deduced from the joint surface for the premaxilla on the nasals.

Exemplars: CMNH 7541 (0), MOR 008 (1).

Phylogeny: Variant of character 11 from Carr et al. (2017); the polarity of the character is reversed here. The ontogenetic juvenile condition corresponds to the phylogenetic condition seen in the *Alioramus* + *Tyrannosaurus* clade, whereas the adult condition is seen in tyrannosauroids outside of that lineage, and in *Daspletosaurus*. This character was discussed as a *T. rex* autapomorphy in Carr (1999).

Naïve hypothesis: Not a recapitulatory character.

7. Premaxilla, body of the bone, width of premaxilla, ratio of body width to body depth (Carr et al., 2017: character 13): narrow, where the body is as dorsoventrally tall as (i.e., ratio greater than 90%) or greater than it is mediolaterally wide (0); wide, where the height of the body is less than its width (i.e., ratio less than 90%) (1).

Exemplars: CMNH 7541 (0), RSM 2523.8 (1).

Phylogeny: Variant of character 13 from Carr et al. (2017) and character 2 of Carrano et al. (2012). Differs from Carr et al. (2017) and Carrano et al. (2012) in that the width to body depth ratio is given, not the depth to length ratio. Also, only two states are given here, in contrast to the three of the other publications. The ontogenetic juvenile condition corresponds to the phylogenetic basal tyrannosauroid state, whereas the adult condition corresponds to that seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

Ontogeny: An ontogenetic character (narrow to wide) from Carr (1999). Character 1 of Carr and Williamson (2004).

8. Premaxilla, maxillary process, dorsal surface, orientation, lateral view (Carr et al., 2017: character 14): widely exposed to view (0), process lies in the horizontal plane and is not in view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

Phylogeny: Variant of character 14 from Carr et al. (2017); the intermediate state of Carr et al. (2017) is excluded here. The ontogenetic juvenile state corresponds to the phylogenetic condition seen in *Bistahieversor* and *Albertosaurus*, whereas the adult condition corresponds to the state seen in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from dorsolateral to lateral.

Ontogeny: The adult state of this character was first described in Carr (1999) for *Daspletosaurus torosus* and *T. rex*.

9. Premaxilla, tooth row, orientation, ventral view (Carr et al., 2017: character 15): more rostrocaudally oriented than mediolaterally oriented (0), more mediolaterally oriented than rostrocaudally oriented (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 15 from Carr et al. (2017); the intermediate state of Carr et al. (2017) is excluded here. The ontogenetic juvenile condition corresponds to the phylogenetic basal tyrannosauroid condition, whereas the adult condition corresponds to the state seen in derived tyrannosauroids (*Xiongguanlong* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from rostrocaudal to mediolateral.

10. Premaxilla, narial fossa, row of foramina along rostral edge of fossa, common groove, rostral and dorsal views (Carr et al., 2017: character 16): present, deep, and distinct (0); absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 16 from Carr et al. (2017); polarity here is reversed and emphasis is given to the common sulcus, which is an osteological correlate of a neurovascular bundle. The ontogenetic juvenile condition corresponds to the derived state of proceratosaurids, whereas the adult conditions corresponds to the state seen in the outgroup and non-proceratosaurid tyrannosauroids.

Naïve hypothesis: Not a recapitulatory character.

11. Premaxilla, medial alveolar process, depth, medial view (Carr et al., 2017: character 19): shallow, where the rostral end is dorsoventrally shorter than the palatal process (0); deep, where the rostral end is as tall as the palatal process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

Phylogeny: Variant of character 19 from Carr et al. (2017); emphasis is given here to the medial alveolar process with the palatal process used as a point of reference to distinguish between the relative heights. The ontogenetic juvenile condition corresponds to the phylogenetic basal tyrannosauroid state, whereas the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Maxilla (18 characters)

12. Maxilla, ridge along the antorbital fossa (=external antorbital fenestra), prominence, lateral view (Carr et al., 2017: character 20): does not obscure the promaxillary fenestra (0); obscures the promaxillary fenestra (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 20 from Carr et al. (2017); emphasis is given to the ridge along the antorbital fossa since it is the causal agent of concealment of the promaxillary fenestra. The ontogenetic juvenile condition corresponds to the phylogenetic condition seen in non-tyrannosaurine tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not obscured to obscured.

Ontogeny: Ontogenetic character 19 of Carr and Williamson (2004).

13. Maxilla, promaxillary fenestra, dorsoventral position relative to the ventral margin of the maxillary fenestra, lateral view (Carr et al., 2017: character 21): a short distance above (0), same level (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Phylogeny: Variant of character 21 of Carr et al. (2017); the position of the fenestra is here assessed relative to the ventral margin of the maxillary fenestra, not to the rostral margin of the external antorbital fossa. The ontogenetic juvenile condition corresponds to the phylogenetic plesiomorphic state seen in basal tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Timurlengia* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from dorsal to ventral.

14. Maxilla, maxillary fenestra, rostrocaudal position, lateral view (Carr et al., 2017: character 22): does not reach the rostral margin of the antorbital fossa (0), reaches the rostral margin of the antorbital fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unaltered character 22 from Carr et al. (2017). The ontogenetic juvenile condition corresponds to the state seen in non-tyrannosaurine tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Zhuchengtyrannus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from caudal to rostral.

Ontogeny: First described in Carr (1999); transition from middle of the antorbital fossa to rostral in position. Ontogenetic character 22 of Carr and Williamson (2004).

15. Maxilla, maxillary fenestra, dorsoventral position, lateral view (Molnar, 1990; Carr et al., 2017: character 23): closely approaches the ventral margin of the fossa (0), dorsal to the ventral margin of the antorbital fossa (1).

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1).

Phylogeny: Variant of character 23 from Carr et al. (2017); polarity is reversed from the phylogenetic homologue. The ontogenetic juvenile condition corresponds to the condition seen in the *Tyrannosaurus* clade, whereas the subadult condition corresponds to tyrannosauroids

outside of that clade. However, the adult condition is a return to the state seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from dorsal to ventral.

Ontogeny: Ontogenetic character 23 of Carr and Williamson (2004).

16. Maxilla, maxillary fenestra, length compared with the length between the rostral margins of the antorbital fossa and antorbital fenestra, lateral view (Carr et al., 2017: character 24): less than half (0), more than half (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 24 of Carr et al. (2017) and character 31 of Currie et al. (2003); the third phylogenetic state (comparison with the orbital fenestra) of Carr et al. (2017) is excluded so that isolated maxillae and specimens lacking complete orbital fenestrae can be included, and so Currie et al. (2003) is followed here. The ontogenetic juvenile condition corresponds to the plesiomorphic state seen in most non-tyrannosaurine tyrannosauroids, whereas the adult condition is seen in the *Alioramus* + derived tyrannosaurine clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from less than half to more than half.

Ontogeny: Variant of character described in Carr (1999); transition from a circular fenestra to a rostrocaudally long fenestra. Variant of ontogenetic character 31 of Carr and Williamson (2004).

17. Maxilla, antorbital fossa, rostradorsal fossa, presence, lateral view (Carr et al., 2017: characters 29, 33): shallow fossa present (0), fossa and recess absent (1), deep penetrating recess is present (2), region obliterated due to expanded maxillary fenestra (3).

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1), MOR 980 (2), CM 9380 (3).

Phylogeny: Variant of characters 29 and 33 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue (#29), two new states are added (#29), and a distinction is made between a fossa and a perforation (#33). The ontogenetic juvenile condition corresponds to the phylogenetic state seen in nontyrannosaurid tyrannosauroids, whereas the more mature conditions correspond to what is seen in tyrannosaurids or in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the transition from absent to present.

Ontogeny: Variant of ontogenetic character 24 of Carr and Williamson (2004).

18. Maxilla, interfenestral strut, rostrocaudal length (width), ratio of rostrocaudal length at its narrowest point to the height of the strut, lateral view (Carr et al., 2017: character 31): wide; length to height ratio is 65% or greater (0); narrow; length to height ratio is less than 65% (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Phylogeny: Variant of character 31 from Carr et al. (2017); the ratio is changed to compare the minimum length to maximum height of the strut. This provides a precise ratio in contrast to comparing the minimum length of the strut to the maximum length of the maxillary fenestra, which itself is variable. The ontogenetic juvenile condition corresponds to what is seen in basal tyrannosauroids, whereas the adult condition corresponds to what is seen in most members of the *Timurlengia* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from wide to narrow.

19. Maxilla, lateral surface of the interfenestral strut, ventral half, lateral view (Carr et al., 2017: character 32): fossa present (0), perforated (1).

Exemplars: RSM 2347.1 (0), LACM 23844 (1).

Phylogeny: Variant of character 32 from Carr et al. (2017); the base of the strut is shallowly excavated, not flat, in all subadults examined. Therefore, the *absent* state, seen in the phylogenetic data set, is excluded here. The ontogenetic juvenile condition corresponds to the phylogenetic state seen in most tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Zhuchengtyrannus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from fossa to perforation.

Ontogeny: First described in Carr (1999); transition from flat to concave. Variant of ontogenetic character 18 of Carr and Williamson (2004).

20. Maxilla, antorbital fossa, region below the internal antorbital fenestra, height, lateral view (Carr et al., 2017: character 35): shallow, the vertical region of the antorbital fossa is shallower than the subcutaneous surface below it for most of its length (0); tall, the antorbital fossa exceeds the subcutaneous surface below it for most of its length (1); extremely shallow, the horizontal ramus is several times deeper than the antorbital fossa in this region (2); caudal end of the fossa is obliterated, where it fades out ahead of the jugal ramus (3). **ORDERED**

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1), CM 9380 (2), AMNH FARB 5027 (3).

Phylogeny: Variant of character 35 of Carr et al. (2017) and character 24 of Carrano et al. (2012); the binary phylogenetic states of *uniform* and *decrease* of Carr et al. (2017) do not precisely capture the ontogenetic changes and so they are accordingly modified here into a multistate character. State two (2) has been added here to the three states described by Carrano et al. (2012); also, the sequence of coding is different, where “absent” is the final state here, whereas it is the intermediate state in Carrano et al. (2012).

The shallow juvenile and adult conditions correspond to what is seen in *Timurlengia*, *Bistahieversor*, *Lythronax*, and *Tyrannosaurus*; in contrast, the tall subadult condition corresponds to what is seen in the rest of Tyrannosauroidea.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from tall to shallow.

21. Maxilla, palatal process, joint surface for the palatine, dorsoventral depth, medial view (Carr et al., 2017: character 40): shallow such that it does not exceed the dorsoventral height of the medial alveolar process below it (0), deep such that it exceeds the dorsoventral height of the medial alveolar process below it (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 40 from Carr et al. (2017); the concealment of the tooth root bulges has been excluded from the character description, as they are exposed to some degree in all growth stages. The ontogenetic juvenile condition corresponds to the plesiomorphic state seen in non-tyrannosaurine tyrannosauroids, whereas the adult condition corresponds to the derived state seen in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Ontogeny: Variant of character described in Carr (1999); progression from ventrally everted to level to raised.

22. Maxilla, nasomaxillary joint surface, form, lateral, ventral, and dorsal views (Carr et al., 2017: character 42): tongue-in-groove (0), peg-in-socket (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 42 from Carr et al. (2017); the coding here is simplified to exclude the *weakly scalloped* state, which is difficult to assess in specimens where the bone is in articulation. Therefore, a straightforward binary approach is used here. The ontogenetic juvenile condition corresponds to the phylogenetic condition seen in non-tyrannosaurine tyrannosauroids, whereas the adult condition is seen in derived tyrannosaurines (*Nanuqsaurus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from tongue-in-groove to peg-in-socket.

Ontogeny: First described in Carr (1999); transition from slotted to peg-in-socket. Variant of ontogenetic character 8 from Carr and Williamson (2004).

23. Maxilla, subcutaneous surface rostral and ventral to the antorbital fossa, texture, lateral view (Carr et al., 2017: character 43): smooth (0), coarse (1).

Exemplars: LACM 28471 (0), CMNH 7541 (1).

Phylogeny: Variant of character 43 from Carr et al. (2017); this character is simplified since the trend of increasing texture cannot be divided into three independent characters. The ontogenetic juvenile condition corresponds to the state seen in non-tyrannosaurine tyrannosauroids, whereas the adult condition is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from smooth to coarse.

Ontogeny: The adult character was first described in Carr (1999) for *D. torosus*.

24. Maxilla, alveolar process, subcutaneous surface, fossae, lateral view (Carr et al., 2017: character 44): lateral fossae absent (0), fossae are present (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 44 from Carr et al. (2017); the fossae and ridges are treated as independent characters here, since it is not yet known if they are, or are not, independent of each other (i.e., pass or fail the test of character congruence). The ontogenetic juvenile condition corresponds to the state seen in most tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Zhuchengtyrannus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

25. Maxilla, alveolar process, subcutaneous surface, ridges, lateral view (Carr et al., 2017: character 44): vertical ridges absent (0), ridges are present (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 44 from Carr et al. (2017); the fossae and ridges are treated as independent characters here, since it is not yet known if they are, or are not, independent of each other (i.e., pass or fail the test of character congruence). The ontogenetic juvenile condition

corresponds to the state seen in most tyrannosauroids, whereas the adult condition corresponds to the state seen in the *Zhuchengtyrannus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

26. Maxilla, circumfossa ridge, presence, lateral view (Carr et al., 2017: character 45):

prominent (0), low or absent (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 45 from Carr et al. (2017); in contrast to the presence/absence approach taken in Carr et al. (2017), the second state is modified to reflect the variation that is seen in adults. The ontogenetic juvenile condition corresponds to the phylogenetic state seen in basal tyrannosauroids (Proceratosauridae to *Dilong*), whereas the adult condition corresponds to the state seen in *Eotyrannus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that corresponds to the phylogenetic transition from prominent to absent.

Ontogeny: First described in Carr (1999); transition from present to absent. Variant of ontogenetic character 19 of Carr and Williamson (2004).

27. Maxilla, maxillary flange, presence, lateral view (Carr et al., 2017: character 47): very low and indistinct (0), distinct (1).

Exemplars: RSM 2347.1 (0), CM 9380: (1).

Phylogeny: Variant of character 47 from Carr et al. (2017); in contrast to the presence/absence approach taken in Carr et al. (2017), the first state is modified to correspond the condition that is seen in subadults and the overall gradation of variation that is seen among specimens.

The presence of a flange corresponds to the derived condition that is seen in *Appalachiosaurus* + Tyrannosauridae, and so ontogenetically there is not an equivalent to the plesiomorphic condition of absence of the flange.

28. Maxilla, horizontal ramus, depth of caudal region, lateral view (Carr et al., 2017: character 48): shallow, where the alveolar region distinctly tapers as it extends caudally (0); deep, where the region tapers slightly (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Phylogeny: Variant of character 48 of Carr et al. (2017); the polarity is reversed from its phylogenetic homologue. The juvenile *shallow* condition corresponds to the condition that is seen in basal tyrannosauroids, whereas the adult condition corresponds to what is seen in *Timurlengia* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that corresponds to the phylogenetic transition from shallow to deep.

Ontogeny: Variant of character described in Carr (1999); transition from shallow alveolar region to a deep alveolar region. Variant of ontogenetic character 21 of Carr and Williamson (2004).

29. Maxilla, palatal process, shape, medial view (Carr et al., 2017: character 51): straight (0), sigmoid and extends rostrorodorsally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Corresponds to character 51 of Carr et al. (2017). The straight juvenile condition corresponds to what is seen in basal tyrannosauroids (*Kileskus* to *Timurlengia*), whereas the sigmoid adult condition corresponds to the condition that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from straight to sigmoid.

Ontogeny: This character was first described in Carr (1999) for *Albertosaurus libratus*.

Nasal (7 characters)

30. Nasal, premaxillary processes, joint surface for premaxillae, proximal extent, dorsal view (Carr et al., 2017: character 54): restricted distally (0), extends proximally (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 54 from Carr et al. (2017); although not identical to character 54, this character may covary with the apposition of the tips of the premaxillae on the nasals (apposed = 0, separate = 1) and so it is included to test that hypothesis.

Result: Characters 30 and 31 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

31. Nasal, premaxillary processes, rostral gap between processes, width and length, dorsal view (Carr et al., 2017: character 54): rostrocaudally short and mediolaterally wide V-shaped gap (0), long and narrow V-shaped gap (1).

Exemplars: LACM 28471 (0), SSM-P 69.4.966 (1).

Phylogeny: Variant of character 54 from Carr et al. (2017); the different versions of the gap might covary with the apposition of the nasal processes of the premaxilla and so this character is included here to test that hypothesis.

Result: Characters 30 and 31 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

32. Nasal, texture of subcutaneous surface A, dorsal view (Carr et al., 2017: character 56): smooth (0), gnarled (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 56 of Carr et al. (2017); here *smooth* is used separately from *slightly rugose* of Carr et al. (2017) to reflect the condition that is seen in juveniles; ergo, *slightly rugose* is subsumed into *gnarled*.

Ontogeny: First described in Carr (1999); transition from smooth to gnarled. Variant of ontogenetic character 6 of Carr and Williamson (2004).

33. Nasal, texture of subcutaneous surface B, dorsal view (Carr et al., 2017: character 56): gnarled, but without prominent crests, ridges, and papillae (0); gnarled, papillae present, but without crests and ridges (1); gnarled with prominent crests, ridges and papillae (2). **ORDERED**

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 56 of Carr et al. (2017); two versions of coarse texture are separated out here by their extremes, to the exclusion of the *smooth* condition of Carr et al. (2017). The juvenile condition corresponds to the condition seen in basal tyrannosauroids (*Dilong* to *Xiongguanlong*) whereas the adult condition corresponds to the condition that is seen in derived tyrannosauroids (*Appalachiosaurus* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low relief to high relief topography.

Ontogeny: Variant of ontogenetic character 6 of Carr and Williamson (2004).

34. Nasal, frontal ramus, mediolateral width A, dorsal view (Carr et al., 2017: character 58): expands caudally (0), parallel-sided (1), tapers caudally (2). **ORDERED**

Exemplars: LACM 28471 (0), SMM-P 69.4.966 (1), AMNH FARB 5027 (2).

Phylogeny: Unmodified character 58 of Carr et al. (2017). The juvenile condition corresponds to the basal tyrannosauroid condition (*Guanlong* to *Dilong*), the intermediate condition corresponds to the state seen from *Eotyrannus* to *Lythronax*, and the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from wide to parallel to narrow.

Ontogeny: First described in Carr (1999); progression from expanded to parallel. Variant of ontogenetic character 9 of Carr and Williamson (2004).

35. Nasal, width of frontal ramus B, dorsal view (Carr et al., 2017: character 59):

unconstricted (0), constricted (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 59 from Carr et al. (2017) that combines the first two states of character 33 and, for the mature state, a threshold ratio is not imposed. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Alioramus*), and the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from unconstricted to constricted.

Ontogeny: Variant of ontogenetic character 9 of Carr and Williamson (2004).

36. Nasal, narial region and rostral end of bone, fossa, presence, lateral and dorsal views (Carr et al., 2017: character 62): premaxillary process and rostral region of bone are coarse (0), a shallow fossa covers the dorsum of the premaxillary processes and extends caudally onto the midregion of the bone (1).

Exemplars: LACM 28471 (0), MOR 555 (1).

Phylogeny: Variant of character 62 from Carr et al. (2017); juvenile state is modified to reflect what is seen in subadults, where a fossa on the ventral margin of the process is not seen. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Eotyrannus*), and the adult condition corresponds to the state seen in the *Appalachiosaurus* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Lacrimal (13 characters)

37. Lacrimal, bone, shape, lateral view (Carr et al., 2017: character 65): T-shaped, where the rostral ramus extends rostrally (0); 7-shaped, where the rostral ramus extends rostroventrally (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of character 65 from Carr et al. (2017) and character 49 of Carrano et al. (2012); the juvenile condition is changed to reflect what is seen in subadult specimens, which

have a distinct supraorbital process. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Albertosaurus*), and the adult condition corresponds to the state that is seen in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from T-shaped to 7-shaped.

38. Lacrimal, cornual process, shape, lateral and dorsal views (Carr et al., 2017: character 66): laterally-extending tab (0), dorsally convex ridge (1), inflated (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Phylogeny: Variant of character 66 from Carr et al. (2017); modified to align with what is seen in the entire growth series where, at no stage is the process absent, and, it is highly modified along the way. The juvenile condition corresponds to the state seen in outgroup taxa, the intermediate condition corresponds to the state seen in nearly all tyrannosauroids (*Proceratosaurus* to *Daspletosaurus*), and the adult condition corresponds to the state seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from laterally extending to distinct to inflated.

Ontogeny: First described in Carr (1999); transition from a weak ridge to a pronounced apex.

39. Lacrimal, cornual process, apex, presence (Carr et al., 2017: characters 68, 71): absent (0), present (1), obliterated by dorsalward inflation (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Phylogeny: Variant of characters 68 and 71 from Carr et al. (2017); modified to correspond to what is seen throughout the growth series, which is initially absent. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Eotyrannus* to *Bistahieversor*), and the intermediate condition corresponds to the state seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Ontogeny: Variant of character described in Carr (1999); progression from three apices to two apices to one apex in *A. libratus* and extreme inflation in *D. torosus* and *T. rex*.

40. Lacrimal, rostral ramus, depth dorsal to the lacrimal recess, lateral view (Carr et al., 2017: character 69): shallower than or as deep as the lacrimal recess (0), deeper than the recess (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of character 69 from Carr et al. (2017); the polarity is reversed from its phylogenetic homologue and a qualitative version is used here instead of the 60% height threshold. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Yutyrannus* to *Appalachiosaurus*) and derived tyrannosaurines (*Daspletosaurus* + *Tyrannosaurus*), and the adult condition corresponds to the state seen in tyrannosaurids (*Albertosaurus* to *Teratophoneus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Ontogeny: Variant of character described in Carr (1999); transition from process lower than recess to process that is as deep as the recess in *A. libratus* and twice as tall in *D. torosus*. Variant of ontogenetic character 35 of Carr and Williamson (2004).

41. Lacrimal, rostral ramus, inflation, lateral view (Carr et al., 2017: character 75): not inflated (0), subcutaneous region is inflated but the antorbital fossa region is not inflated (1), fossa is inflated (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

Phylogeny: Variant of character 75 of Carr et al. (2017); a state is added to the *inflated by pneumatic recess* condition to reflect what is seen among subadult and adult specimens. The juvenile condition corresponds to the state seen in all tyrannosauroids aside from the *Daspletosaurus* + *Tyrannosaurus* clade, and the subadult and adult conditions corresponds to what is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not inflated to inflated.

Ontogeny: Variant of ontogenetic character 38 of Carr and Williamson (2004).

42. Lacrimal, lacrimal pneumatic recess, size, lateral view (Carr et al., 2017: character 76): small (0), large (1).

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1).

Note: In the *small* condition the recess extends a short distance ahead of the rostral margin of the ventral ramus and it is dorsoventrally shallow; in the *large* condition the recess extends a great distance ahead of the ventral ramus and it is dorsoventrally tall throughout most of its length.

Phylogeny: Unmodified character 76 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Yutyranus*, *Guanlong*) and tyrannosaurines (*Alioramus*, *Daspletosaurus* + *Tyrannosaurus*), and the subadult condition is seen in intermediate grade tyrannosauroids (*Dilong* to *Teratophoneus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from small to large, followed by a reversal to the small condition.

43. Lacrimal, rostral ramus, antorbital fossa, number of accessory recesses rostral to the lacrimal pneumatic recess, lateral view (Carr et al., 2017: character 78): two (0), one (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 78 from Carr et al. (2017); modified to reflect the conditions seen in subadult and adult specimens, where at no stage are accessory recesses absent.

44. Lacrimal, medial pneumatic recess, presence, medial view (Carr et al., 2017: character 79): absent (0), present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Unmodified character 79 of Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Eotyrannus* to *Albertosaurus*) and the adult condition corresponds to the state seen in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

45. Lacrimal, supraorbital ramus, length, lateral view (Carr et al., 2017: character 82): long (at least as long as deep or longer than deep) (0), short (shorter than deep) (1).

Note: In part equivalent to the “swollen above orbits” observation made by Bakker et al. (1988).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of character 82 of Carr et al. (2017); this character is split into the separate characters of length and height to test whether or not they change together. The polarity of length is reversed from its phylogenetic homologue. The *long* juvenile condition corresponds to the state seen in some basal tyrannosauroids (*Yutyranus*) and in all derived tyrannosauroids (*Bistahieversor* + *Tyrannosaurus*). The *short* adult condition is seen in intermediate grade tyrannosauroids (*Guanlong*, *Dilong*, *Xiongguanlong*).

Naïve hypothesis: Weak recapitulatory character, where the long to short transition is seen between proceratosaurids and intermediate-grade basal tyrannosauroids, and no reduction in length is seen within derived tyrannosauroids.

Result: Characters 45 and 46 were optimized unambiguously on the ontogram at the same growth stage; they almost certainly represent an oversplit character.

46. Lacrimal, supraorbital process, depth, lateral and caudal views (Carr et al., 2017: character 82): shallow, not inflated (0); deep, inflated dorsally (1); extreme dorsalward swelling (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

Note 1: For the *extreme* condition, the dorsum must extend into view above the rugose lateral surface of the supraorbital process.

Note 2: In part equivalent to the “swollen above orbits” observation made by Bakker et al. (1988).

Phylogeny: Variant of character 82 of Carr et al. (2017); this character is split into the separate characters of length and height to test if they change together. The shallow juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*) and the deep adult condition corresponds to the state seen in derived tyrannosauroids (*Bistahieversor* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Result: Characters 45 and 46 were optimized unambiguously on the ontogram at the same growth stage; they almost certainly represent an oversplit character.

47. Lacrimal, ventral ramus, caudal margin, subocular process, presence, lateral view (Carr et al., 2017: character 83): absent (0), present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of character 83 from Carr et al. (2017); this character has been simplified from a multistate to a binary absence/presence character since the process is subtle in all cases where it is present. The juvenile condition corresponds to the state seen in intermediate grade tyrannosauroids (*Eotyrannus*, *Xiongguanlong*) and the adult condition is seen in all other tyrannosauroids.

Naïve hypothesis: Weak recapitulatory character that corresponds to the transition between intermediate grade tyrannosauroids and the *Appalachiosaurus* + Tyrannosauridae clade.

48. Lacrimal, supraorbital ramus, joint surface for the frontal, form, medial view (Carr et al., 2017: characters 86, 87): flat (0), conical (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of characters 86 and 87 from Carr et al. (2017); these characters have been combined into one, since the conical form is an epiphenomenon of pneumatic inflation. The

juvenile condition corresponds to the state seen in *Albertosaurus* and the adult condition corresponds to the state seen in more derived tyrannosaurids.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from flat to conical.

49. Lacrimal, jugal contact, length of rostroventral ala compared with that of the ventral ramus, lateral view (Carr et al., 2017: character 88): ramus is shorter than ala (0), ramus is longer than ala (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

Phylogeny: Variant of character 88 of Carr et al. (2017); this character has been changed from a quantitative definition to a qualitative format. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Eotyrannus*) and the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from a long ala to a short ala.

Ontogeny: First described in Carr (1999); transition from ala contact is longer than the ventral ramus to contacts are equal in length. Variant of ontogenetic character 36 of Carr and Williamson (2004).

Jugal (13 characters)

50. Jugal, maxillary ramus, depth, dorsoventral height, lateral view (Carr et al., 2017: character 90): shallow (0), deep (1).

Note: The *maxillary ramus* is the region that includes the lateral and medial maxillary processes that join within the antorbital fossa of the jugal. The ramus includes the region that overlaps the rostroventral lamina of the lacrimal, but excludes the region of the jugal that is overlapped laterally by the ventral ramus of the lacrimal. Ergo, the maxillary ramus includes the left and right maxillary processes, the antorbital fossa of the jugal, the jugal pneumatic recess, and the secondary fossa. The region below the ventral ramus of the lacrimal is best considered to be the rostral end of the body of the bone.

Note: A correlate of *shallow* is where the rostradorsal margin of the ramus extends caudodorsally at a low angle, whereas a correlate of *deep* is where the margin extends at a steep caudodorsal angle.

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 90 from Carr et al. (2017), aside from the osteological point of reference given in the second note. The juvenile condition corresponds to the state seen in intermediate grade tyrannosauroids (*Xiongguanlong* to *Lythronax*) and the adult condition corresponds to the condition seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*) and in tyrannosaurines.

Naïve hypothesis: Recapitulatory character that corresponds to the transition from shallow to deep.

Ontogeny: First described in Carr (1999); transition from shallow to deep. Variant of ontogenetic character 40 of Carr and Williamson (2004).

51. Jugal, jugal pneumatic recess, caudal margin position, lateral view (Carr et al., 2017: character 92): ahead of joint surface for ventral ramus of the lacrimal (0), at or immediately ahead of the level of the rostral end of the ventral ramus or below the joint surface (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of character 92 of Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen among most tyrannosaurids and the adult condition corresponds to the state seen in basal tyrannosauroids and *Albertosaurus libratus*, *Alioramus* spp., and *T. bataar*.

Naïve hypothesis: Weak recapitulatory character that corresponds to the transition seen between basal and derived tyrannosaurines or to the transition between nontyrannosaurid tyrannosauroids.

52. Jugal, jugal pneumatic recess, lateral margin, direction, lateral view (Carr et al., 2017: character 93; variant of Currie et al., 2003): extends caudodorsally at a low angle (i.e., more caudal than dorsal) (0), extends caudodorsally at a steep angle (i.e., more dorsal than caudal) (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: This difference in angle almost certainly correlates with the dorsoventral deepening of the maxillary ramus; ergo, the “caudal” margin seen in adults is homologous to the “ventral” margin seen in subadults, where both extend along the subcutaneous surface. Therefore, the caudal margin of the recess cannot be said to be the result of reabsorption of bone, but rather by reorientation that results from a shape change (contra Carr, 1999).

Phylogeny: Unmodified character 93 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Alioramus*) and the adult condition corresponds to the state seen in derived tyrannosaurines (*Daspletosaurus*, *Raptorex*).

Naïve hypothesis: Recapitulatory character that corresponds to the phylogenetic transition from low to steep.

Ontogeny: First described in Carr (1999); transition from not resorbed to resorbed.

53. Jugal, jugal pneumatic recess, overall form, lateral view (Carr et al., 2017: character 95): slit-like (secondary fossa is marginally exposed to view) (0), oval (fossa extends rostradorsally widely into view) (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: The shape of the opening is almost certainly the result of dorsoventral deepening, not absorption since, in both states, the ventral (0) or caudal (1) margin is adjacent to the subcutaneous surface.

Note: The *slit-like* condition and *oval* condition are homologous to the “small” and “large” states of Currie (2003).

Phylogeny: Unmodified character 95 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosaurids (*Albertosaurus*, *Lythronax*) and the adult condition corresponds to the condition seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and tyrannosaurines.

Naïve hypothesis: Recapitulatory character that corresponds to the phylogenetic transition from slit-like to oval.

Ontogeny: Variant of ontogenetic character 41 of Carr and Williamson (2004).

54. Jugal, body, joint surface for the lacrimal, caudal half, orientation, medial view (Carr et al., 2017: character 96): low rostroventral angle (i.e., more rostral than ventral) (0), steep rostroventral angle (i.e., more ventral than rostral) (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Unmodified character 96 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in nearly all tyrannosauroids and the adult condition corresponds to the state seen in *Dilong*, *Albertosaurus*, and *Daspletosaurus horneri*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to steep, but indicates that the phylogenetic coding (Carr et al., 2017) for *T. rex* might be in error.

55. Jugal, postorbital process, lateral depression, presence, lateral view (Carr et al., 2017: character 97): absent (0); present, but vanishingly shallow (1); shallow and enhanced by ridges (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 555 (2).

Phylogeny: Variant of character 97 of Carr et al. (2017); a new state has been added to include the condition that is seen in juveniles. The intermediate condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Alioramus*) and the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to coarse.

Ontogeny: First described in Carr (1999); transition from convex to concave. Variant of ontogenetic character 42 of Carr and Williamson (2004).

56. Jugal, joint surface for the postorbital, position of distal end, lateral view (Carr et al., 2017: character 98): dorsal to orbit floor (0); dorsal, inset, and braced by a small prong-like process above orbit floor (1); dorsal, inset, and braced by a large prong-like process above orbit floor (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

Note: The presence of the prong-like process is homologous to the “tetragonal” shape described by Carpenter (1992).

Phylogeny: Variant of character 98 from Carr et al. (2017); juvenile state modified to reflect the relative dorsoventral position of the joint surface. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*), the intermediate condition corresponds to the state seen in basal tyrannosaurids (*Albertosaurus* to *Alioramus*), and the adult condition corresponds to the state seen in tyrannosaurines (*Lythronax* to *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic progression from prong-like process absent to present.

Ontogeny: First described in Carr (1999); transition from floor of orbital fenestra to dorsal to the floor.

57. Jugal, postorbital process, orientation, lateral view (Carr et al., 2017: character 101): caudodorsal (0), vertical (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of character 101 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*) and the adult condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Xiongguanlong* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from caudodorsal to vertical.

Ontogeny: First described in Carr (1999); transition from caudodorsally declined to erect.

58. Jugal, dorsal quadratojugal process, orientation, lateral view (Carr et al., 2017: character 105): caudoventral or horizontal (0), caudodorsal (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 105 from Carr et al. (2017), aside from the *caudoventral* state added to the juvenile condition. The juvenile condition corresponds to the state seen in tyrannosauroids outside of the clade *Tyrannosaurus*, the adult condition corresponds to the state seen in *Tyrannosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from horizontal to caudodorsal.

59. Jugal, orbit margin, slope toward the joint surface for the lacrimal, lateral view (Carr et al., 2017: character 107): extends rostr dorsally at a low angle (0), extends abruptly rostr dorsally (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Phylogeny: Variant of character 107 of Carr et al. (2017), where the locus of the difference is emphasized.

Ontogeny: First described in Carr (1999); transition from level to concave. Variant of ontogenetic character 43 of Carr and Williamson (2004) where the emphasis is placed on the orientation of the rostral half of the margin instead of the shape of the margin, which does not capture the causal difference between states. The juvenile condition corresponds to the state seen in tyrannosauroids outside of the clade *Tyrannosaurus*; the adult condition corresponds to the state seen in *Tyrannosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to steep.

60. Jugal, dorsal quadratojugal process, tip, proximity to vertical shaft of the quadratojugal, lateral view (Carr et al., 2017: character 134): does not reach the vertical shaft (0), reaches the vertical shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 134 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Alioramus*) and the adult condition corresponds to the state seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic progression from short to long.

61. Jugal, rostral end of the joint surface for the quadratojugal, lateral view (Carr et al., 2017: character 135): pointed (0), squared off (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 135 from Carr et al. (2017), where the *rounded* intermediate state is excluded here, producing a binary character. The juvenile condition corresponds to the condition seen in basal tyrannosauroids (*Proceratosaurus* to *Alioramus*) and the adult condition corresponds to the state seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from pointed to deep.

62. Jugal, joint surface for the quadratojugal, position relative to the laterotemporal fenestra, lateral view (Carr et al., 2017: character 136): extends far ahead of the rostral margin of the laterotemporal fenestra (0), extends only a short distance ahead of the margin of the fenestra (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of character 136 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Xiongguanlong* + Tyrannosauridae) and the adult condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Postorbital (9 characters)

63. Postorbital, cornual process, development, lateral view (Carr et al., 2017: character 110): low rugosity (0), prominent rugosity (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Phylogeny: Variant of character 110 of Carr et al. (2017), where the original multistate character is simplified to its binary condition. The juvenile condition corresponds to the state seen in *Alioramus*, and the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to distinct. The low, coarse patch seen in some juvenile specimens might correspond to the absent phylogenetic state, which is seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*); if true, then this character is congruent with the phylogenetic progression from absence of the process to the presence of a large process.

Ontogeny: First described in Carr (1999); transition from depression to boss (*Albertosaurus libratus*), and irregular surface to boss (*T. rex*). Variant of ontogenetic character 46 of Carr and Williamson (2004).

64. Postorbital, cornual process, position relative to orbit, lateral view (Carr et al., 2017: characters 110, 112): at orbit margin (0), caudal to orbit margin (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of characters 110 and 112 of Carr et al. (2017); modified from character 110 where the position of the process is treated here as independent from its size, whereas this is unmodified from character 112. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Yutyranus* to *Alioramus*) and the adult condition corresponds to the state seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from at the orbit margin to caudal to the margin.

65. Postorbital, cornual process, height, lateral view (Carr et al., 2017: character 111): does not exceed dorsal margin of the bone (0), exceeds the dorsal margin of the bone (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

Phylogeny: Variant of character 111 from Carr et al. (2017); in adult state, the process exceeds the dorsal margin. The juvenile condition corresponds to the state seen in basal tyrannosaurids (*Albertosaurus* to *Teratophoneus*) and the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to tall.

Ontogeny: The adult character state was first described in Carr (1999) for *D. torosus*.

66. Postorbital, subocular process, presence, lateral view (Carr et al., 2017: character 116): absent (0), present and indistinct (1), present and distinct (2). **ORDERED**

Exemplars: CMNH 7541(0), BMRP 2002.41 (1), AMNH FARB 5027 (2).

Phylogeny: Variant of character 116 from Carr et al. (2017) and character 58 of Carrano et al. (2012) that includes a transitional state. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*) and the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Ontogeny: First described in Carr (1999); transition from absent to present. Variant of ontogenetic character 47 of Carr and Williamson (2004).

67. Postorbital, subocular process, position, lateral view (Carr et al., 2017: character 117): distally positioned (0), proximally positioned (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 117 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Bistahieversor* to *Teratophoneus*) and the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from distal to proximal.

68. Postorbital, frontal process, length, lateral view (Carr et al., 2017: characters 118, 119): long (0), short (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Phylogeny: Variant of characters 118 and 119 from Carr et al. (2017); length and height have been separated into two independent characters here as a test of whether or not they covary. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and the adult condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Xiongguanlong* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from long to short.

Ontogeny: First described in Carr (1999); transition from long to short. Variant of ontogenetic character 48 of Carr and Williamson (2004).

Result: Characters 68 and 69 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

69. Postorbital, frontal process, depth, lateral view (Carr et al., 2017: characters 118, 119): shallow (0), deep (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Phylogeny: Variant of characters 118 and 119 from Carr et al. (2017); length and height have been separated into two independent characters here as a test of whether or not they covary. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*) and the adult condition corresponds to the state seen in derived tyrannosaurines.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Ontogeny: First described in Carr (1999); transition from shallow to deep. Variant of ontogenetic character 49 of Carr and Williamson (2004).

Result: Characters 68 and 69 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

70. Postorbital, jugal process rostrocaudal length (= ‘width’) relative to the ventral ramus of the lacrimal, lateral view (Carr et al., 2017: character 120): narrow, same width as ventral ramus of lacrimal (0); wider than ventral ramus of lacrimal (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Unmodified character 120 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Yutyranus*, *Guanlong*) and the adult condition corresponds to the state seen in *Dilong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

Ontogeny: First described in Carr (1999); transition from slender to broad (=rostrocaudally wide). Variant of ontogenetic character 52 of Carr and Williamson (2004).

71. Postorbital, postorbital osteoderm, lateral view (Carr et al., 2017: character 121): not fused (0), fused (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 121 from Carr et al. (2017) and character 61 from Carrano et al. (2012), where presence/absence has been changed to unfused or fused. Whether or not it is actually absent or present, the *unfused* condition is scored for juveniles that lack a clear joint surface for the osteoderm. The juvenile condition corresponds to the state seen in tyrannosauroids outside of *Tyrannosaurus*, which corresponds to the adult condition.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from unfused to fused.

Squamosal (5 characters)

72. Squamosal, quadratojugal process, distal end, dorsoventral depth, lateral view (Carr et al., 2017: character 125): shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 125 from Carr et al. (2017) that is unmodified aside from the state descriptions; i.e., *shallow* instead of *tapered point* and *deep* instead of *squared off*. The juvenile condition corresponds to the state seen in *Bistahieversor* and *Albertosaurus*, and the adult condition corresponds to the state seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

73. Squamosal, joint surface for the quadratojugal, dorsoventral height, lateral view (Carr et al., 2017: character 126): shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 126 of Carr et al. (2017); three states are reduced here to two, where the *flange absent* state is excluded given that the joint surface is present in all growth stages. The juvenile condition corresponds to the state seen in *Bistahieversor* and the adult condition corresponds to the state seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

74. Squamosal, caudal process, inflation, lateral view (Carr et al., 2017: character 127): not inflated, deep groove separates it from body of bone (0); inflated, groove is shallow (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unmodified character 127 of Carr et al. (2017), aside from the addition of the correlate of the groove. The juvenile condition corresponds to the state seen in tyrannosauroids less derived than the *Daspletosaurus* + *Tyrannosaurus* clade, the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not inflated to inflated.

75. Squamosal, caudal process, inflation, distal view (Carr et al., 2017: character 127): narrow, widens at joint surface of quadrate (0); base is widened (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 127 of Carr et al. (2017); this character is in reference to the width of the process at the joint surface for the quadrate to assess whether or not it covaries with the groove that becomes reduced with increased inflation of the process. The juvenile condition corresponds to the state seen in tyrannosauroids less derived than the *Daspletosaurus* + *Tyrannosaurus* clade; the adult condition corresponds to the state seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

76. Squamosal, pneumatic foramen in ventral surface, presence, ventral view (Carr et al., 2017: character 131): absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: The presence of the foramen requires, at least, one undercut edge; the structure is a fossa unless an edge, or part of an edge, is undercut.

Phylogeny: Unmodified character 131 from Carr et al. (2017), aside from the simpler state descriptions. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Albertosaurus sarcophagus*) and the adult condition corresponds to the state seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Quadratojugal (3 characters)

77. Quadratojugal, squamosal process, ridge along rostral margin of lateral surface, form, lateral view (Carr et al., 2017: character 133): present, subtle, and fades in strength dorsally (0); present, large, and extends to the dorsal margin of the bone (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Phylogeny: Variant of character 133 from Carr et al. (2017), where the multistate is reduced here to a binary character given that the ridge is seen in all growth stages. The juvenile condition corresponds to the state seen in basal tyrannosaurid-line tyrannosauroids (*Xiongguanlong* to *Albertosaurus*) and the adult condition corresponds to the state seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from subtle to prominent.

78. Quadratojugal, vertical shaft, quadrate fossa, depth, caudal view (Carr et al., 2017: character 137): deep (0), shallow (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Variant of character 137 from Carr et al. (2017), where the fossa is coded as present in juveniles, not *flat* as it is in its phylogenetic homologue. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*) and the adult condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Xiongguanlong* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

79. Quadratojugal, shaft, foramen in lateral surface, presence, lateral view (Carr et al., 2017: character 140): present (0), absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 140 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the condition seen among the *Daspletosaurus* + *Tyrannosaurus* clade and the adult condition corresponds to the state seen in less derived tyrannosauroids.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Quadrate (2 characters)

80. Quadrate, ventral joint surface for the quadratojugal, dorsal half of the medial margin, orientation, caudal view (Carr et al., 2017: character 147): extends vertically (0), extends dorsolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 147 from Carr et al. (2017), aside from the *dorsomedial* orientation, which is not seen. The juvenile condition corresponds to the state seen in tyrannosauroids aside from *Albertosaurus* and the adult condition corresponds to the condition that is seen in that clade. This suggests that *T. rex* is phylogenetically miscoded for this character.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from vertical to dorsolateral, if, and only if, *T. rex* is phylogenetically miscoded.

81. Quadrate, medial fossa, caudoventral corner, depth, medial view (Carr et al., 2017: character 148): deeply concave caudoventral corner (0); deep, but caudoventral corner is not excavated (1); shallow, caudoventral corner not deeply recessed (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 1125 (2).

Phylogeny: Variant of character 148 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Bistahieversor*, *Albertosaurus*) and the adult state corresponds to the condition that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from deep to shallow.

Prefrontal (1 character)

82. Lacrimal, joint surface for the prefrontal, length, medial view (Carr et al., 2017: character 150): extends only a short distance down the ventral ramus, does not extend below proximal caudomedial foramen (0); extends below level of the proximal caudomedial foramen (1), extends to the level of the distal caudomedial foramen (2). **ORDERED**

Exemplars: FMNH PR2411 (0), MOR 1125 (1), CM 9380 (2).

Phylogeny: Variant of character 150 from Carr et al. (2017); polarity differs from its phylogenetic homologue and the neurovascular foramina of the caudal surface of the ventral ramus are used as stable reference points. Also, an intermediate condition is included. The juvenile condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae and the adult condition corresponds the state seen in *T. bataar*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from limited to extensive.

Frontal (9 characters)

83. Frontal, shape of apposed bones, dorsal view (Carr et al., 2017: character 151): long and wide nasal ramus, main body slightly expanded laterally (0); small triangular nasal ramus, main body rectangular (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Note: This character is homologous to the width of the nasal processes, which are either not compressed (juvenile condition) or compressed mediolaterally (adult condition).

Phylogeny: Unmodified character 151 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and the adult condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Timurlengia* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from long and wide to small and triangular.

Ontogeny: First described in Carr (1999); transition from longer than wide to wider than long. Variant of ontogenetic character 55 of Carr and Williamson (2004).

84. Frontal, dorsotemporal fossa, length relative to the exposed part of the bone, dorsal view (Carr et al., 2017: character 155): less than 50% (0), greater than or equal to 50% (1).

Exemplars: LACM 28471 (0), RSM 2523.8 (1).

Phylogeny: Variant of character 155 from Carr et al. (2017); character is reduced here from multistate to binary, using the threshold of 50%. The juvenile condition corresponds to the state

seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and the adult condition corresponds to the state seen in tyrannosaurid-line tyrannosauroids (*Timurlengia* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to long.

85. Frontal, sagittal crest, presence, dorsal and lateral views (Carr et al., 2017: character 157): absent (0), present and low (1), present and tall (2). **ORDERED**

Exemplars: DDM 344.1 (0), LACM 238471 (1), AMNH FARB 5027 (2).

Note: In the *low* condition the crest is a low, but distinct ridge, whereas in the *tall* condition the ridge is a tall crest. Within the *tall* category, a distinction can be made between tall and short states (see next character, #85).

Phylogeny: Variant of character 157 from Carr et al. (2017); the presence and structure states have been separated out here to test whether or not they covary. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Dilong* to *Alioramus*) and the adult state corresponds to the state seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to tall.

Ontogeny: Variant of ontogenetic character 58 of Carr and Williamson (2004).

86. Frontal, sagittal crest, height, lateral view (Carr et al., 2017: character 157): tall (0), low (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: This character is in reference to the condition seen in subadults and adults, excluding the ridge-like or absent states that are seen in juveniles.

Phylogeny: Variant of character 157 from Carr et al. (2017); the presence and structure states have been separated out here to test whether or not they covary. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Dilong* to *Alioramus*) and the adult state corresponds to the state seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to tall.

Result: Characters 86 and 87 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

87. Frontal, sagittal crest, form, dorsal view (Carr et al., 2017: character 157): single unit structure (0), a pair of parallel crests (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 157 from Carr et al. (2017); the presence and structure states have been separated out here to test whether or not they covary. The juvenile condition corresponds to the state seen in basal tyrannosaurines (*Lythronax* to *Daspletosaurus*) and the adult condition corresponds to the state seen in *Tyrannosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from single to paired.

Ontogeny: The adult state of this character was first described in Carr (1999) for *T. rex*. Variant of ontogenetic character 58 of Carr and Williamson (2004).

Result: Characters 86 and 87 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

88. Frontal, ratio of length of the sagittal crest to the length of the bone, dorsal view (Carr et al., 2017: character 158): 37% or less (0), greater than or equal to 37% (1).

Exemplars: DDM 344.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 158 from Carr et al. (2017), where the threshold value has been changed from 25% to 37%, which is based on data that are specific to *T. rex*. The juvenile condition corresponds to the condition seen in basal tyrannosauroids (*Dilong* to *Alioramus*) and the adult condition corresponds to the condition seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to long.

89. Frontal, joint surface for the postorbital, differentiation, dorsal view (Carr et al., 2017: character 159): differentiation between buttress and shelf is indistinct (0), clear differentiation between buttress and shelf (1; Currie et al., 2003).

Exemplars: LACM 28471 (0), CMNH 7541 (1).

Note: This character is equivalent to whether or not the buttress is distinct in dorsal view.

Phylogeny: Variant of character 159 from Carr et al. (2017); the multistate phylogenetic homologue is here modified to a binary character, where the relative height of the joint surface is excluded. The juvenile condition corresponds to the state seen in outgroup taxa and the adult condition is seen in tyrannosaurid-line tyrannosauroids (*Timurlengia* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from differentiation absent to present.

Ontogeny: Variant of ontogenetic character 56 of Carr and Williamson (2004).

90. Frontal, orbital notch, form, lateral view (Carr et al., 2017: character 160): notch extends rostradorsally to span the entire height of the bone between the joint surfaces for the lacrimal and the postorbital (0); notch is pinched out laterally by the conjoined joint surfaces for the lacrimal and postorbital, although the notch has limited expression as it extends toward the dorsal and ventral surfaces of the bone (1); the notch is completely pinched out by the conjoined joint surfaces, but with a small dorsal expression as a stout groove in the dorsolateral edge of the bone (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

Phylogeny: Variant of character 160 from Carr et al. (2017), where the condition of the transit of the orbital notch, between dorsal and ventral surfaces, is included. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong*, *Dilong*), the intermediate and adult conditions corresponds to the state seen in the *Xiongguanlong* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from visible to pinched out.

Ontogeny: Variant of character from Carr (1999); transition from a margin to a slot.

91. Frontal, forehead, slope in mediolateral section, dorsal and rostral views (Carr et al., 2017: character 161): flat (0), medioventral slope (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

Phylogeny: Variant of character 161 from Carr et al. (2017); the intermediate state of the phylogenetic homologue (*mediodorsal slope*) is excluded given that it is not seen in *T. rex*. The

juvenile condition corresponds to the state seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*) and the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from flat to medioventral slope.

Ontogeny: First described in Carr (1999); transition from flat to dorsomedial in *A. libratus* and medioventral orientation in *D. torosus* and *T. rex*.

Parietal (3 characters)

92. Parietal, rostral margin, shape, dorsal view (Carr et al., 2017: character 162): wedge-shaped (0), transverse (1).

Exemplars: LACM 28471 (0), CMNH 7541 (1).

Phylogeny: Variant of character 162 from Carr et al. (2017); polarity reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen from *Timurlengia* to *Daspletosaurus* and the adult condition is seen in *Tyrannosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from wedge-shaped to transverse.

Ontogeny: Variant of ontogenetic character 70 of Carr and Williamson (2004).

93. Parietal, nuchal crest, inverted triangle above the nuchal ridge, size, caudal view (Carr et al., 2017: character 170): absent (0), present but not prominent (1), prominent and caudally bulging (1). **ORDERED**

Exemplars: LACM 28471 (0), CMNH 7541 (1).

Phylogeny: Variant of character 170 from Carr et al. (2017), where the states have been simplified to presence/absence of the triangular ridge. The juvenile condition corresponds to the state that is seen in non-*Tyrannosaurus* tyrannosauroids and the adult condition corresponds to the state that is seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Result: Characters 93 and 94 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

94. Parietal, nuchal crest, inverted triangle, lateral grooves, presence, caudal view (Carr et al., 2017: character 170): absent (0), present (1).

Exemplars: MOR 1125 (0), AMNH FARB 5117 (1).

Phylogeny: Variant of character 170 from Carr et al. (2017), where the presence of the grooves is treated independently to test whether or not they covary with the presence of the triangular ridge. The juvenile condition corresponds to the state that is seen in non-*Tyrannosaurus* tyrannosauroids and the adult condition corresponds to the state that is seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Result: Characters 93 and 94 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

Vomer (3 characters)

95. Vomer, rostral process, width, dorsal and ventral views (Carr et al., 2017: character 172): narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 172 from Carr et al. (2017), aside from the simpler state descriptions. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Daspletosaurus*) and the adult condition corresponds to the state seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

Ontogeny: This character was described in Carr (1999) for *A. libratus*, *D. torosus*, and *T. rex*.

Result: Characters 95 and 96 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

96. Vomer, rostral process, lateral margins, rostromedial angle, dorsal and ventral views (Carr et al., 2017: character 172): distinct rostromedial angle (0); low rostromedial angle, nearly parallel (1); secondarily distinct angle from widened process (2).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

Phylogeny: Variant of character 172 from Carr et al. (2017), where the shape of the rostral process is treated as an independent character to test whether or not it covaries with width. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Daspletosaurus*) and the adult condition corresponds to the state seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from distinct to secondarily distinct.

Result: Characters 95 and 96 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

97. Vomer, stem, dorsoventral depth, lateral view (Carr et al., 2017: character 173): deep (0), long and shallow (1).

Exemplars: CMNH 7541 (0), RSM 2523.8 (1).

Phylogeny: Variant of character 173 from Carr et al. (2017), where the polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen in Tyrannosauridae and the adult condition corresponds to the state seen in *A. sarcophagus* and *T. rex*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from deep to shallow.

Ectopterygoid (5 characters)

98. Ectopterygoid, jugal process, caudal surface, perforation, caudal view (Carr et al., 2017: character 175): not perforated by a foramen (0), perforated by a foramen (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unmodified character 175 from Carr et al. (2017). The juvenile condition corresponds to the state seen in tyrannosauroids less derived than *Tyrannosaurus* and the adult condition corresponds to the state seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from imperforate to perforated.

99. Ectopterygoid, jugal process, inflation of proximal end, dorsal view (Carr et al., 2017: character 176): not inflated (0), inflated (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unmodified character 176 from Carr et al. (2017), aside from emphasizing the proximal end to test whether or not inflation is instantaneous. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Guanlong*, *Appalachiosaurus*, *Bistahieversor*) and the adult condition corresponds to the condition seen in *Xiongguanlong* and Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not inflated to inflated.

Result: Characters 99 and 100 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

100. Ectopterygoid, jugal process, inflation of distal end, dorsal view (Carr et al., 2017: character 176): not inflated (0), inflated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Variant of character 176 from Carr et al. (2017), aside from emphasizing the distal end to test whether or not inflation is instantaneous. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Guanlong*, *Appalachiosaurus*, *Bistahieversor*) and the adult condition corresponds to the condition that is seen in *Xiongguanlong* and Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not inflated to inflated.

Result: Characters 99 and 100 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

101. Ectopterygoid, pneumatic recess, caudal half of recess, width, ventral view (Carr et al., 2017: character 177): narrow and tapers along its entire extent to a point (0), wide and tapers close to its caudal margin (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Unmodified character 177 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Albertosaurus*) and the adult condition corresponds to the state that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

102. Ectopterygoid, pneumatic recess, dorsal margin, bounded by a ridge, presence, ventral view (Carr et al., 2017: character 178): bounded by low ridge (0), bounded by a prominent ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Variant of character 178 from Carr et al. (2017), where the ridge is present in all growth stages. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Albertosaurus*) and the adult condition corresponds to the state that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to prominent.

Palatine (5 characters)

103. Palatine, vomeropterygoid ramus, angle, lateral view (Carr et al., 2017: character 180): extends at a low angle rostr dorsally (0), vertical (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Unmodified character 180 from Carr et al. (2017). The juvenile condition corresponds to the condition that is seen in all tyrannosauroids aside from *Albertosaurus* and the adult condition corresponds to the state that is seen in *Albertosaurus*, which indicates that *T. rex* is miscoded as having the rostr dorsolateral orientation.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from rostr dorsolateral to vertical, with the revision that the vertical condition is present in *T. rex*.

104. Palatine, caudal pneumatic recess, caudal margin position, lateral view (Carr et al., 2017: character 183): ahead of the caudal margin of the vomeropterygoid ramus (0), extends caudal to the ramus (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 183 from Carr et al. (2017), where the polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in *Appalachiosaurus* and the clade *Albertosaurus*, and the adult condition is seen in all other tyrannosauroids.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from ahead to caudal if, and only if, a rostr dorsolateral orientation is plesiomorphic for Tyrannosauridae.

105. Palatine, dorsolateral process, joint surface for the lacrimal, distance from the caudal pneumatic recess, lateral view (Carr et al., 2017: character 185): closely approaches (0), widely separated (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 185 from Carr et al. (2017), where the polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae and the adult condition corresponds to the state that is seen in outgroup taxa (*Yutyranus*, *Appalachiosaurus*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

106. Palatine, dorsolateral process, dorsal process, inflation, lateral and dorsal views (Carr et al., 2017: character 187): not inflated (0), inflated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Phylogeny: Unmodified character 187 from Carr et al. (2017). The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus*) and *Alioramus*, and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not inflated to inflated.

107. Palatine, lateral flange, dorsal and ventral views (Carr et al., 2017: character 188): notch does not separate the lateral flange from the body of the bone (0), a narrow notch separates the two structures (1), a wide notch separates the structures (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

Phylogeny: Variant of character 188 from Carr et al. (2017), where the brace is present in all growth stages that shows a progressive increase in lateralward width. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Eotyrannus* to *Albertosaurus*) and the intermediate and adult conditions correspond to the state that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to wide.

Supraoccipital (1 character)

108. Supraoccipital, dorsal process, forked condition, presence, caudal view (Carr et al., 2017: character 194): not forked (0), forked (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 194 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in non-*Tyrannosaurus* taxa and the adult condition is seen in that clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from not forked to forked.

Ontogeny: The adult state of this character was first described in Carr (1999) for *T. rex*.

Otoccipital (1 character)

109. Otoccipital, paroccipital process, caudal surface dorsolateral to the occipital condyle, fossa, presence, caudal view (Carr et al., 2017: character 200): region is flat (0); region is deeply concave and the caudodorsal surface above it is strongly convex, a condition produced almost certainly by internal inflation (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

Phylogeny: Unmodified character 200 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Timurlengia*) and the adult condition corresponds to the state that is seen in *Xiongguanlong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from flat to concave.

Basioccipital (2 characters)

110. Basioccipital, subcondylar fossa, medial margin, undercut, presence, caudal view (Carr et al., 2017: character 207): proximal region along the fossa is gently undercut (0), fossa is not undercut at all (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of character 207 from Carr et al. (2017), where the undercut of the fossa into the ascending scar is emphasized. The juvenile condition corresponds to the state seen in *Bistahieversor* to *Daspletosaurus* and adult condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Xiongguanlong*) and the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from undercut to not undercut.

111. Basioccipital, subcondylar fossa, depth, caudal view (Carr et al., 2017: character 207): deep (0), shallow (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Phylogeny: Variant of character 207 from Carr et al. (2017), where the polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state seen in *Bistahieversor* to *Daspletosaurus* and adult condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Xiongguanlong*) and the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from deep to shallow.

Ontogeny: The adult state of this character was first described in Carr (1999) for *T. rex*.

Basisphenoid (1 character)

112. Cultriform process, height, lateral view (Carr et al., 2017: character 213): low (0), tall (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Phylogeny: Unmodified character 213 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong*) and *Alioramus*, and the adult condition corresponds to the state seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to tall.

Basisphenoid Recess (1 character)

113. Basisphenoid recess, closure, caudal and ventral views (Carr et al., 2017: character 209): partly closed (0), completely closed (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Phylogeny: Variant of character 209 from Carr et al. (2017) and character 95 from Carrano et al. (2012); simplified here from a multistate to a binary character, which corresponds to states 1 and 2 of its phylogenetic homologue. Polarity of states 1 and 2 are reversed between the sources. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Daspletosaurus*) and the adult condition corresponds to the state that is seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from partly closed to completely closed.

Endocranium (1 character)

114. Endocranium, cochlear duct, length and width, lateral view (Carr et al., 2017: character 225): long and thin (0), short and wide (1).

Exemplars: CMNH 7541(0), AMNH FARB 5029 (1).

Phylogeny: Variant of character 225 of Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in tyrannosaurid-line tyrannosauroids (*Xiongguanlong* + Tyrannosauridae) and the adult condition corresponds to the state that is seen in outgroup taxa.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Mandibular Ramus (1 character)

115. Mandibular ramus, dorsoventral depth of dentary at level of dentary-surangular contact on the dorsal margin of the lower jaw, lateral view (Carr et al., 2017: character 226): less than or equal to 20% of the total anteroposterior length of the lower jaw (0), greater than 20% of the length of the lower jaw (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 226 from Carr et al. (2017); threshold here is increased from 18% to 20% to reflect what is seen in *T. rex*. The juvenile condition corresponds to the condition that is seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*) and *Alioramus*, and the adult condition is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Craniomandibular Joint (1 character)

116. Craniomandibular joint, dorsoventral position, lateral view (Carr et al., 2017: character 228): ventral, below the dorsal edge of the mandibular ramus and the adductor and orbital regions of the cranium (0); positioned above the lower edge of the adductor and orbital regions (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 228 from Carr et al. (2017), where the point of reference is changed from the alveolar margin of the dentary to the mandibular ramus, and here also includes the orbital and adductor regions of the cranium as an extra point of reference. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*) and the adult condition corresponds to the condition that is seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from ventral to dorsal.

Dentary (9 characters)

117. Dentary, chin, position relative to alveoli, lateral and medial views (Carr et al., 2017: character 229): below the fourth alveolus (0), ahead of the fourth alveolus (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

Phylogeny: Variant of character 229 from Carr et al. (2017), where the point of reference is the fourth alveolus and the shape of the rostral margin is disregarded, and the polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in *Proceratosaurus*, *Yutyranus*, *Appalachiosaurus* to *Alioramus*, *Nanuqsaurus*, and the *Tyrannosaurus* clade (*T. rex* is almost certainly miscoded as having a chin below the fourth alveolus). The adult condition corresponds to the condition that is seen in basal tyrannosauroids (*Guanlong* to *Eotyrannus*) and intermediate tyrannosaurines (*Teratophoneus curriei*, *Daspletosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from caudal to rostral.

118. Dentary, flange rostroventral to Meckelian foramen that delimits the caudoventral limit of the abutting symphyseal surface, presence, medial view (Carr et al., 2017: character 230): low (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 230 from Carr et al. (2017), where the flange is present in all growth stages and shows an increase in relative development. The juvenile condition is comparable to the state that is seen in basal tyrannosauroids (*Yutyranus*, *Eotyrannus*) and the adult condition corresponds to the state that is seen in *Dilong* and in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to distinct.

119. Dentary, symphysis, rostral margin, medial view (Carr et al., 2017: character 231): fringed by a low irregular ridge that fades below midheight (0), ridge is strongly developed into a series of ridges that fade below midheight (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unmodified character 231 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Eotyrannus* to *Teratophoneus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from subtle to coarse.

Ontogeny: First described in Carr (1999); transition from flat to rugose.

120. Dentary, ventral bar, joint surface for the splenial below Meckelian fossa, form, medial view (Carr et al., 2017: character 232): longitudinal ridges and grooves (0), peg-in socket (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

Phylogeny: Variant of character 232 from Carr et al. (2017), where the texture is emphasized, whereas the dorsoventral height is excluded. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Teratophoneus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from smooth to coarse.

121. Dentary, mesial alveoli, size relative to alveoli at middle of tooth row, dorsal view (Carr et al., 2017: character 233): first two alveoli are substantially smaller (0), first alveolus is substantially smaller (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

Phylogeny: Variant of character 233 from Carr et al. (2017). Only states 1 and 2 are seen in *T. rex*; therefore, state 0 is excluded. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Daspletosaurus*) and the adult condition corresponds to the state that is seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from a small to large second dentary tooth.

122. Dentary, dorsal row of foramina, distinct groove, presence, lateral view (Carr et al., 2017: characters 234): absent (0), present along entire foramen row (1), partially absent (2).

ORDERED

Exemplars: AMNH FARB 5050 (0), RSM 2523.8 (1), UWBM 99000 (2).

Note: The groove is scored as present in specimens where the groove is partly absent.

Phylogeny: Variant of character 234 from Carr et al. (2017) and character 124 from Carrano et al. (2012), where the emphasis is on presence/absence, not relative depth. The subadult condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Guanlong*), and the juvenile and adult conditions corresponds to the state that is seen in outgroup taxa and in *Dilong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

123. Dentary, Meckelian groove, depth, medial view (Carr et al., 2017: character 236):

shallow (0), deep (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Phylogeny: Variant of character 236 from Carr et al. (2017), where the mediolateral depth is retained, but dorsoventral height is excluded since a difference in relative height is not seen. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Eotyrannus*, *Dryptosaurus*) and the adult condition is seen in *Timurlengia* and *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Ontogeny: Variant of ontogenetic character 82 of Carr and Williamson (2004).

124. Dentary, chin, angle, lateral view (Carr et al., 2017: character 237): angle low (0), steep (in lateral view the dorsal and ventral margins of the bone diverge toward the rostral margin of the bone) (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 237 from Carr et al. (2017); polarity reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Alioramus*) and the adult condition corresponds to the state that is seen in the *Teratophoneus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from a low angle to a steep angle.

125. Dentary, lump caudal to chin, presence, medial view (Carr et al., 2017: character 238): absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Unmodified character 238 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Bistahieversor* to *Teratophoneus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Ontogeny: This character was first described in Carr (1999) for *D. torosus* and *T. rex*.

Surangular (4 characters)

126. Surangular, caudal surangular foramen, size, lateral view (Carr et al., 2017: character 239): large (0), small (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: The region caudodorsal to the foramen is dorsoventrally shallower than the foramen in the *large* form, whereas that region is significantly deeper than the opening in the *small* state.

Phylogeny: Variant of character 239 from Carr et al. (2017); polarity reversed from its phylogenetic homologue. The juvenile condition corresponds to the condition that is seen in the *Timurlengia* + Tyrannosauridae clade and the adult condition is seen in basal tyrannosauroids (*Proceratosaurus* to *Eotyrannus*). The state in *T. rex* is miscoded as large, whereas it should be coded as small.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition, owing to a reversal.

Ontogeny: Variant of character first described in Carr (1999); transition from small to large.

127. Surangular, surangular shelf, lateral extension, orientation, lateral view (Carr et al., 2017: character 241): horizontal (0), lateroventral (1), dorsolateral (2).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: This refers to the direction the shelf takes as it extends out from the lateral surface of the bone; it does *not* refer to the rostrocaudal orientation of the shelf.

Phylogeny: Variant of character 241 from Carr et al. (2017); the plesiomorphic state of the phylogenetic homologue is excluded. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Kileskus*, *Yutyranus*, *Dilong*, *Timurlengia*) and the adult condition (lateroventral) corresponds to the state that is seen in *Eotyrannus* and the *Dryptosaurus* + Tyrannosauridae clade. The dorsolateral condition lacks a homologue.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from horizontal to lateroventral.

Ontogeny: First described in Carr (1999); transition from horizontal to lateroventral. Variant of ontogenetic character 74 of Carr and Williamson (2004).

128. Surangular, surangular shelf, rostrocaudal orientation, lateral view (Carr et al., 2017: character 242): horizontal (0), slants rostr dorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Phylogeny: Variant of character 242 from Carr et al. (2017); the intermediate phylogenetic state, which is not seen in *T. rex*, is excluded. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and the adult condition corresponds to the condition that is seen in *Yutyranus* and the *Dryptosaurus* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from horizontal to rostr dorsally.

Ontogeny: First described in Carr (1999); transition from horizontal to rostr dorsally. Variant of ontogenetic character 76 of Carr and Williamson (2004).

129. Surangular, caudal surangular foramen, caudal margin, embayment, presence, lateral view (Carr et al., 2017: character 243): present (0), reduced or absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: The view is taken here that the embayment is apneumatic, which differs from the view of other authors (Gold et al., 2013).

Phylogeny: Variant of character 243 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in

Bistahieversor + Tyrannosauridae and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Timurlengia*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition owing to a reversal.

Splénial (1 character)

130. Splénial, rostral mylohyoid foramen, shape, medial view (Carr et al., 2017: character 251): long and low (0), long and dorsoventrally tall (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Phylogeny: Variant of character 251 from Carr et al. (2017) and character 129 from Carrano et al. (2012); the plesiomorphic phylogenetic state of Carr et al. (2017) is excluded from here, and the small and large states of Carrano et al. (2012) are not used, given that a large opening is seen in all growth stages of *T. rex*. The juvenile condition corresponds to the state that is seen in *Appalachiosaurus* and *Alioramus*, and the adult condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Dentition (4 characters)

131. Premaxillary teeth, lingual surface, lingual ridge, presence, lingual view (Carr et al., 2017: character 259): distinct ridge (0); lingual surface is evenly convex, reducing or obliterating the ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

Phylogeny: Variant of character 259 from Carr et al. (2017); the polarity is reversed from its phylogenetic homologue and the intermediate state is excluded. The juvenile condition corresponds to the state that is seen in derived tyrannosauroids (*Eotyrannus* + Tyrannosauridae) and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Proceratosaurus* to *Dilong*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

132. Maxilla, dental alveoli, number, ventral view (Carr et al., 2017: character 261): 15 (0), 16 (1), 12 (2), 11 (3). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), CM 9380 (2), LACM 23844 (3).

Phylogeny: Variant of character 261 from Carr et al. (2017) and character 153 of Carrano et al. (2012) to accommodate the different tooth counts that are seen in *T. rex*. The juvenile and subadult conditions corresponds to the states seen in basal tyrannosauroids (*Proceratosaurus* to *Yutyrannus*, *Timurlengia* to *Albertosaurus*, *Daspletosaurus*) and the subadult and adult conditions correspond to the state that is seen in *Lythronax*, *Teratophoneus*, and the *Zhuchengtyrannus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition of a reduction in maxillary tooth count.

Ontogeny: Variant of ontogenetic character 34 of Carr and Williamson (2004).

133. Dentary, dental alveoli, number, dorsal view (Carr et al., 2017: character 263): 16 (0), 17, (1), 14 (2), 13 (3), 12 (4). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 1125 (2), CM 9380 (3), MOR 555 (4).

Phylogeny: Variant of character 263 from Carr et al. (2017) to accommodate the different tooth counts that are seen in *T. rex*. The ontogenetic states do not strictly correspond to the phylogenetic characters, but a reduction in tooth count in both is seen. The juvenile condition (17 alveoli or more) corresponds to the condition seen in outgroups and the basal tyrannosauroid *Proceratosaurus*, the mature condition (fewer than 17 alveoli) corresponds to the condition that is seen in tyrannosauroids more derived than *Proceratosaurus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from many teeth to fewer.

134. Maxillary teeth, maximum labiolingual width to mesiodistal length ratio, excluding the first two maxillary teeth (Carr et al., 2017: character 264): ziphiform, 0.56 or lower (0); incrassate, 0.65 or greater (1).

Note: The incrassate form is equivalent to the term *caniniform* of Carr and Williamson (2004).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 264 from Carr et al. (2017); the threshold is changed from 60% to 56% and 65%, to reflect the ratios seen in *T. rex*. The juvenile condition corresponds to the state seen in basal tyrannosauroids (*Proceratosaurus* to *Bistahieversor* and the adult state corresponds to the condition that is seen in derived tyrannosauroids (*Xioongguanlong*, *Albertosaurus*, *Alioramus sinensis*, *Daspletosaurus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from ziphiform to incrassate.

Ontogeny: Variant of character described in Carr (1999) for *A. libratus* and *D. torosus*. Variant of ontogenetic character 84 of Carr and Williamson (2004).

Cervical Vertebrae

Axis (9 characters)

135. Axis centrum complex (odontoid+axial intercentrum+axial pleurocentrum), anteroposterior length to dorsoventral height ratio, lateral view (Carr et al., 2017: character 266): anteroposteriorly longer than tall (0), dorsoventrally taller than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 266 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Xioongguanlong*) and the adult condition corresponds to the state that is seen in Tyrannosauridae (aside from *Alioramus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to tall.

136. Axis, pneumatic foramen, surrounding fossa, extent and depth, lateral view (Carr et al., 2017: character 268): vanishingly shallow and limited to the margins of foramen (0); extensive, a deep, funnel-like fossa that occupies the upper third to half of the centrum that opens anteroventrolaterally, foramen is located at its posterodorsal corner (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 268 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Alioramus*) and the adult condition corresponds to what is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

137. Axis, ridge on ventral surface of axial pleurocentrum, ventral view (Carr et al., 2017: character 269): low, flat, and coarse hourglass-shaped surface, where the anteroventral surface of the centrum is flat posterior to the axial intercentrum and it is separated by a low mediolaterally extending ridge from the rest of the ventral surface of the centrum (0); the anteroventral surface of the centrum is convex, coarse, and continuous with the rest of the ventral surface of the centrum behind it, and the flat surface and ridge are absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 269 from Carr et al. (2017), where the ridge is seen in subadults and so an absence/presence approach is inapplicable. The juvenile condition almost certainly corresponds to the condition that is seen in basal tyrannosauroids (*Dilong* to *Xiongguanlong*) and the adult condition almost certainly corresponds to the condition that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from deep to shallow.

138. Axis, lamina, pneumatic recess, size, anterior view (Carr et al., 2017: character 270): small pneumatic foramen located posterior to the prezygapophysis and dorsal to the transverse process without reaching the lateral edge of the lamina or approaching the interspinous ligament scar medially, and extends no further posteriorly than the transverse process (0); intermediate sized foramen that extends anteriorly to the posterior edge of the joint surface of the prezygapophysis, does not extend medially across the prespinal fossa, extends laterally to the lamina that connects the pre- and postzygapophyses (i.e., does not reach the lateral edge of the lamina), extends posteriorly to a half (left) or third (right) of the lamina that extends between the pre- and postzygapophyses (i.e., does not reach the anterior margin of the joint surface of the postzygapophyses) (1); massive and extensive excavation that anteriorly reaches the posterior edge of the prezygapophysis, extends to the lateral edge of the lamina, extends medially to extend along the lateral edge of the interspinous ligament scar, and extends posteriorly above the level of the anterior end of the joint surface of the postzygapophysis (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), FMNH PR2081 (2).

Phylogeny: Variant of character 270 from Carr et al. (2017), where the foramen is present in all growth stages and a progression through the three states is seen.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic progression.

139. Axis, spinous process, dorsal region of anterior surface, texture, anterior view (Carr et al., 2017: character 271): subtle texture (0); highly rugose, with series of grooves, ridges, and eminences (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 271 from Carr et al. (2017), except the smooth condition is not seen. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Xiongguanlong*) and *Alioramus*, and the adult condition corresponds to the state that is seen in *Bistahieversor* and the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic progression from subtle to coarse.

140. Axis, spinous process, form and orientation, lateral view (Carr et al., 2017: character 273): dorsoventrally shallow and extends at a low (~45 degree) posterodorsal angle (0), dorsoventrally tall and extends at a steep angle (greater than 45 degrees) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 273 from Carr et al. (2017), where the emphasis is given to dorsoventral height and posterodorsal angle. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong*, *Dilong*) and the adult condition corresponds to the state that is seen in *Xiongguanlong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow and low to tall and steep.

141. Axis, supradiapophyseal fossa (fossa posterodorsal to diapophysis), form, lateral view (Carr et al., 2017: character 274): shallow (0), deeply excavated and funnel-like (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 274 from Carr et al. (2017), except the fossa is present in all growth stages. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Daspletosaurus*) and the adult condition corresponds to the state that is seen in the *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the transition from shallow to deep.

142. Axis and anterior-middle postaxial cervicals, epiphysis, length, lateral view (Carr et al., 2017: character 275): does not extend posterior to postzygapophysis or extends only a short distance posteriorly (0), extends far posterior to zygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 275 from Carr et al. (2017) and character 92 of Rauhut (2003), where an epiphysis that extends beyond the postzygapophyses is seen in subadults. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Alioramus*) and the adult condition corresponds to the state that is seen in the *Teratophoneus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic progression from short to long.

143. Axis and anterior-middle postaxial cervicals, epiphysis, shape, lateral and dorsal views (Carr et al., 2017: character 276): dorsoventrally flat flange or small, ridge-like mound (0); large, rugose flange (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 276 from Carr et al. (2017) and character 92 of Rauhut (2003), aside from the flange-like condition that is seen in subadults. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Juratyran*) and *Alioramus*, and the adult condition corresponds to the state that is seen in derived tyrannosaurines (*Teratophoneus* + *Tyrannosaurus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from small to large.

Postaxial Cervical Vertebrae (5 characters)

144. Cervical vertebrae, spinous process in middle to posterior cervicals, shape, dorsal view (Carr et al., 2017: character 277): anteroposteriorly longer than mediolaterally wide (0), mediolaterally wider than long and have an overall triangular shape in anterior view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 277 from Carr et al. (2017), where the process is wider than long in adults and the shape, as seen from the front, is included. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Xiongguanlong*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

145. Cervical vertebrae, spinous process in middle to posterior cervicals, dorsoventral height, lateral view (Carr et al., 2017: character 278): shorter than the posterior centrum surface (0), taller than posterior centrum surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 278 from Carr et al. (2017), although the process is either shorter or taller than the centrum, not the same height as is seen in its phylogenetic apomorphic homologue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Xiongguanlong*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to tall.

146. Cervical vertebrae, posterior centrodiapophyseal laminae in anterior to middle cervicals, form, lateral view (Carr et al., 2017: character 279): a weak ridge above a vanishingly shallow infradiapophyseal fossa (0); a distinct, laterally offset lamina that delimits a deep infradiapophyseal fossa (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 279 from Carr et al. (2017), where the depth of the infradiapophyseal fossa is included in the juvenile condition. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Xiongguanlong*) and the adult condition corresponds to the state that is seen in Tyrannosaurinae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

147. Cervical vertebrae, centrum, hypapophysis on anterior region of ventral surface, anterior and ventral views (Carr et al., 2017: character 280): absent (0), present and distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 280 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Juratyant*) and the adult condition corresponds to the state that is seen in *Xiongguanlong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

148. Cervical vertebrae, posterior centrodiapophyseal lamina in anterior to middle cervicals, lateral view (Carr et al., 2017: character 282): nearly horizontal, fossa located primarily above lamina (0); projects posteroventrally, infrapostzygapophyseal fossa located primarily posterior to lamina (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 282 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Juratyran*) and the adult condition corresponds to the state that is seen in the *Xiongguanlong* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from horizontal to posteroventral.

Dorsal Vertebrae (1 character)

149. Dorsal vertebrae, posterior dorsals, spinous process, level of posterior termination, lateral view (Carr et al., 2017: character 285): anterior to posterior centrum face (0), same level as posterior centrum face (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 285 from Carr et al. (2017). The condition of “far posterior to the posterior centrum face” is not seen in either exemplar specimen; the adult ontogenetic state corresponds to its plesiomorphic phylogenetic homologue. Also, the juvenile state is added here.

Naïve hypothesis: A nonrecapitulatory character that is incongruent with the phylogenetic transition.

Note: Both conditions are seen in the exemplar specimen BMRP 2002.4.1 and so the presence of the anterior position is taken to represent the juvenile condition. The mere presence of this state in the subadult, and its absence from adults, justifies the coding of “0.”

Sacrum (2 characters)

150. Sacrum, sacral vertebra five, hyposphene in SV5, form, posterior view (Carr et al., 2017: character 294): present and comprised of two parallel-sided sheets (0), present as a single midline structure (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 294 from Carr et al. (2017); the polarity of this character is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in Tyrannosaurinae (indicating that it is miscoded in *T. rex*) and the adult condition corresponds to the condition that is seen in basal tyrannosauroids (*Guanlong*, *Juratyran*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

151. Sacrum, fenestrae between fused neural spines, closure, lateral view (Carr et al., 2017: character 290): fenestra between processes two and three is open dorsally and ventrally, fenestra between processes three and four is open ventrally, fenestra between four and five is open (0); fenestra between processes three and four is nearly entirely pinched out where only the ventral extent is open, fenestra between processes four and five is closed dorsally and bridged at midheight, all other fenestrae are closed (1).

Exemplars: CM 9380 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 290 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in Tyrannosaurinae and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus*, *Guanlong*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Caudal Vertebrae (3 characters)

152. Caudal vertebrae, anterior caudals, spinous process, anteroposterior position of base, lateral view (Carr et al., 2017: character 295): above posterior edge of posterior surface of centrum (0), anterior to posterior edge of centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 295 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in *Yutyranus* and in Tyrannosaurinae (which indicates that the character is miscoded for *T. rex*) and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Juratyant*, *Albertosaurus*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

153. Caudal vertebrae, anterior caudals, shape of transverse processes, dorsal and ventral views (Carr et al., 2017: character 296): distal end expanded into a spatulate flange (0), gradual expansion in width distally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 296 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the condition seen in Tyrannosaurinae (indicates that *T. rex* is miscoded) and the adult condition corresponds to the condition that is seen in basal tyrannosauroids (*Yutyranus* to *Bistahieversor*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

154. Caudal vertebrae, anterior caudals, number of laminae linking prezygapophysis and transverse process, lateral view (Carr et al., 2017: character 297): one (0); two, which form a triangular fossa between the laminae (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 297 from Carr et al. (2017), where the presence of one lamina is documented for the juvenile condition. The juvenile condition corresponds to the condition that is seen in basal tyrannosauroids (*Yutyranus* to *Juratyant*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

Scapula (2 characters)

155. Scapula, angle between acromion process and anterior edge of shaft (viewed with the long axis of the bone held vertically), lateral view (Carr et al., 2017: character 298): approximately 90 degrees (0), greater than 90 degrees (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 298 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae (indicating that *T. rex* is almost certainly miscoded) and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Eotyrannus*).

Naïve hypothesis: Nonecapitulatory character that is incongruent with the phylogenetic transition.

156. Scapula, acromion, length of long axis (extends normal to the long axis of the bone), lateral view (Carr et al., 2017: character 299): short (0), long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: In the *short* condition the acromion is anteroposteriorly longer than dorsoventrally tall, whereas in the *long* condition it is taller than long.

Phylogeny: Variant of character 299 from Carr et al. (2017) and character 220 from Carrano et al. (2012), whereas the length of the process is not quantified here. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Eotyrannus*) and the adult condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to long.

Coracoid (1 character)

157. Coracoid, anteroposterior length at midpoint (with the scapulocoracoid long axis held horizontally), relative to the anteroposterior length of the acromion of the scapula, lateral view (Carr et al., 2017: character 303): short, where the ratio is 1.32 (0); intermediate, where it is 1.8 (1); long, where the ratio is 2.1 (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), FMNH PR2081 (2).

Phylogeny: Variant of character 303 from Carr et al. (2017), where the ratios reflect what is seen in *T. rex*. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Eotyrannus*) and the adult condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from short to long.

Humerus (3 characters)

158. Humerus, deltopectoral crest, apex, location from proximal end, lateral view (Carr et al., 2017: character 307): 27% (0), equal to or greater than 31% (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 307 from Carr et al. (2017); the states here are encapsulated by the intermediate state of their phylogenetic homologue.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition if that trend is a shift from the shaft midlength to a more proximal position.

159. Humerus, additional muscle attachment tubera at the corner of the anterior and lateral surface distal to the deltopectoral crest, relative development, anterolateral view (Carr et al., 2017: character 309): subtle (0), prominent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 309 from Carr et al. (2017), where the tubera are present in all growth stages of *T. rex*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition if the trend is found to be from subtle to prominent tubera.

160. Humerus, distal medial condyle, form, anterior view (Carr et al., 2017: character 311): does not extend a great distance medially, is not ‘hooked’ in appearance (0); extends a great distance medially, is ‘hooked’ in appearance (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 311 from Carr et al. (2017), but without mention of the lateral condyle. The juvenile condition corresponds to the state that is seen in outgroup taxa, basal tyrannosaurids (*Albertosaurus* to *Teratophoneus*) and the *Tyrannosaurus* clade (indicating that the condition in *T. rex* is miscoded), and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Eotyrannus*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Ilium (11 characters)

161. Ilium, linear ridge dorsal to the acetabulum, form, lateral view (Carr et al., 2017: character 324): present and distinct (0), present but indistinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 324 from Carr et al. (2017), character 172 of Rauhut (2003), and character 263 from Carrano et al. (2012); the polarity of this character is reversed from its phylogenetic homologues. The juvenile condition corresponds to the state that is seen in nearly all tyrannosauroids aside from *Alioramus sinensis*, indicating that *T. rex* is miscoded and the adult condition corresponds to the condition that is seen in outgroup taxa and *A. sinensis*.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

162. Ilium, preacetabular process, anteroventral hook, presence (Carr et al., 2017: character 326): present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 326 from Carr et al. (2017); polarity of the coding is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in Tyrannosauridae (indicating that *T. rex* is miscoded) and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Sinotyrannus* to *Aviatyrannis*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

163. Ilium, acetabular antitrochanter, form, lateral view (Carr et al., 2017: character 328): limited in extent, where it extends marginally along the margin of the acetabulum and is weakly demarcated from the ischial peduncle (0); extensive, where it wraps posteroventrally onto the posterolateral surface of the ischial peduncle and is distinctly demarcated from the ischial peduncle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 328 from Carr et al. (2017), where it is present in all growth stages and the mature condition differs slightly from the description of its phylogenetic homologue in that its posterolateral extent is emphasized here. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Sinotyrannus* to *Xiongguanlong*) with the exception of *Yutyranus*, and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from limited to extensive.

164. Ilium, acetabular crest, posterior end, maximum lateral extension relative to the ischial peduncle, ventral view (Carr et al., 2017: character 329): extends marginally a short distance laterally (0); juts posterolaterally as a distinct, triangular process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 329 from Carr et al. (2017); polarity is the reverse of its phylogenetic homologue and in both cases the crest is mediolaterally narrower than the entire ischial peduncle. The juvenile condition corresponds to the condition that is seen in *Xiongguanlong* + Tyrannosauridae (indicating that *T. rex* might be miscoded) and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Aviatyrannis*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

165. Ilium, acetabular crest, extent on pubic peduncle, lateral view (Carr et al., 2017: character 330): extensive, extends slightly more than halfway down the peduncle (0); limited, stops above the midheight of the peduncle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 330 from Carr et al. (2017); in both cases the anterior end of the crest is sharply offset from the acetabular edge of the peduncle. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Aviatyrannis*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from extensive to limited.

166. Ilium, pubic peduncle, ventral margin that abuts the pubis, orientation with the bone held horizontally, lateral view (Carr et al., 2017: character 333): a low anterodorsal angle (0), horizontal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 333 from Carr et al. (2017); polarity of coding is reversed from its phylogenetic analogue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Sinotyrannus* to *Aviatyrannis*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from anterodorsal to horizontal.

167. Ilium, dorsal margin, shape, lateral view (Carr et al., 2017: character 335): subtly convex for its entire length, and the dorsoventral height of the entire bone is nearly uniformly

dorsoventrally deep anteroposteriorly (0); convex anteriorly and levels out posteriorly, where the anterior half of the bone is distinctly dorsoventrally deeper than the posterior region (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 335 of Carr et al. (2017) and character 279 from Carrano et al. (2012). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Sinotyrannus* to *Xiongguanlong*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from subtly convex to distinctly convex.

168. Ilium, postacetabular process, posterior margin, shape, lateral view (Carr et al., 2017: character 336): nearly the entire margin extends anterodorsally (0); the ventral half is convex but trends vertically, whereas the dorsal half extends anterodorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 336 of Carr et al. (2017); the states described here reflect the variation seen in the apomorphic state of its phylogenetic homologue.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

169. Ilium, ratio of anteroposterior length to dorsoventral depth above acetabulum, lateral view (Carr et al., 2017: character 337): long and low, ratio of 3.3 (0); tall, ratio of 2.8 (1)

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 337 from Carr et al. (2017); the ratios are changed to reflect what is seen in *T. rex*. The juvenile condition corresponds to what is seen in basal tyrannosauroids (*Sinotyrannus* to *Aviatyrannis*) and the adult condition corresponds to the state that is seen in *Xiongguanlong* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to tall.

170. Ilium, linear ridge dorsal to acetabulum, dorsal extent, lateral view (Carr et al., 2017: character 338): extends more than halfway up the bone toward the dorsal edge of the ilium (0), fades a short distance above the midheight of the blade and does not closely approach the dorsal edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 338 from Carr et al. (2017); in the juvenile condition, the ridge does not reach the dorsal edge of the bone, unlike its phylogenetic homologue where it does reach the edge.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

171. Ilium, brevis fossa, orientation, lateral view (Carr et al., 2017: character 340): widely exposed in lateral view such that it is visible along nearly the entire length of the postacetabular process (0); narrowly exposed in lateral view, exposed along the anterior end of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 340 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in all tyrannosauroids except for *Juratyran* + *Stokesosaurus*

and *Aviatyrannis*, to which the adult condition corresponds (indicates that *T. rex* might be miscoded).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Pubis (1 character)

172. Pubis, pubic tubercle, size, lateral view (Carr et al., 2017: character 345): a low convexity on the anterolateral edge of the pubis (0); a distinct convexity, especially at its dorsal end, that extends from the anterolateral edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 345 from Carr et al. (2017), where the structure in *T. rex* corresponds to the apomorphic condition and has two states. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyrannus* to *Juratyran*) and the adult condition corresponds to the state that is seen in Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from low to distinct.

Ischium (3 characters)

173. Ischium, ischial tubercle, form, lateral view (Carr et al., 2017: character 353): lens-shaped and interrupts the posterodorsal margin of the bone as a low convexity (0); a rectangular, anterodorsally extending scar whose anterodorsal margin sharply interrupts the posterodorsal margin of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 353 from Carr et al. (2017), where it is limited to the apomorphic states of its phylogenetic homologue.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

174. Ischium, distal end, expansion, presence, lateral view (Carr et al., 2017: character 354): distal end is not dilated (0), distal end is dilated and forms a posterolaterally extending knob (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 354 from Carr et al. (2017) and character 193 from Rauhut (2003); coding is the reverse of its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids from *Yutyrannus* to *Juratyran* and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

175. Ischium, shaft, curvature, lateral view (Carr et al., 2017: character 358): distinctly curved such that it bows dorsally throughout its extent (0), straight (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 358 from Carr et al. (2017); polarity of the coding is reversed from its phylogenetic analogue. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyrannus* to *Appalachiosaurus*), *Alioramus*, and the *Daspletosaurus* +

Tyrannosaurus clade (indicating that *T. rex* might be miscoded), and the adult condition corresponds to the state that is seen in outgroup taxa, *Albertosaurus* and *Teratophoneus*.
Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

Femur (3 characters)

176. Femur, proximal margin, form, posterior view (Carr et al., 2017: character 361): approximately straight (0); subtly concave (1); concave, due to a greater trochanter that is elevated substantially relative to the lateral portion of the proximal surface of the head (2).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

Phylogeny: Unmodified character 361 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Alioramus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from straight to concave.

177. Femur, posterior surface of the head, trochanteric fossa, form, posterior view (Carr et al., 2017: character 362): shallow fossa (0); deep, extensive, and triangular depression that covers most of the posterior surface of the femur proximally and is demarcated medially and ventrally by a pronounced, curving, and swollen ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 362 from Carr et al. (2017), aside from excluding the intermediate state, which is incorporated into the juvenile character description. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Alioramus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

178. Femur, extensor groove, form, anterior and distal views (Carr et al., 2017: character 366): shallow and wide concave surface in distal view (0); deep, U-shaped cleft in distal view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 366 from Carr et al. (2017), aside from excluding the plesiomorphic state. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Juratyrant*) and the adult condition corresponds to the state that is seen in the *Xiongguanlong* + Tyrannosauridae clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from shallow to deep.

Tibia (5 characters)

179. Tibia, ratio of tibia length relative to that of the femur (Carr et al., 2017: character 369): greater than or equal to 93% (0), less than 93% (1)

Exemplars: MOR 1125 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 369 from Carr et al. (2017) in that the threshold is changed from 1.05 and 1.0 to 0.93 to correspond to the ratio that is seen in *T. rex*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from long to short.

180. Tibia, lateral condyle of proximal end, anterior process, presence, proximal view

(Carr et al., 2017: character 370): absent (0), present (1).

Exemplars: BMRP 2001.4.70 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 370 from Carr et al. (2017). Although the process in the juvenile exemplar is present, as seen in lateral view as a stout, anteroventrally-extending process, it does not extend anteriorly when viewed from above and so it is absent in that view. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Juratyran*) and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from absent to present.

181. Tibia, cnemial crest, orientation and position relative to proximal condyles, medial

view (Carr et al., 2017: character 371): extends at a low anterodorsal angle, elevating the crest a short distance above the condyles (0); extends steeply anterodorsally, greatly elevating the crest above the condyles (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 371 from Carr et al. (2017); in both cases here, the crest extends proximal to the condyles, that is not seen in the apomorphic state of its phylogenetic homologue; the polarity of the characters is reversed. The juvenile condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Juratyran*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

182. Tibia, lateral malleolus, lateral extent, anterior view (Carr et al., 2017: character 372):

narrow, mediolateral measure is less than 40% of mediolateral width of adjacent shaft (0); wide, mediolateral width is equal to or greater than 40% of the width of the adjacent shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 372 from Carr et al. (2017). The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Dryptosaurus*) and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae (except *Alioramus*).

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

183. Tibia, lateral malleolus, position relative to medial malleolus (Carr et al., 2017:

character 373): extends to approximately the same level distally (0), lateral malleolus extends significantly further distally than medial malleolus (1).

Exemplars: DDM 35.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 373 from Carr et al. (2017). The juvenile condition

corresponds to the state that is seen in outgroups and the adult condition corresponds to the state that is seen in Tyrannosauroidae, aside from *Dilong* and *Alioramus*.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from proximal to distal.

Pes

Metatarsal II (2 characters)

184. Metatarsal II, joint surface for metatarsal III on distal part of lateral surface, form, lateral view (Carr et al., 2017: character 381): concave, lightly coarse fossa that occupies the entire length of the shaft distally (=ventrally), and is less than half the height of the shaft (0); a shallowly concave, lightly rugose fossa that occupies the entire anteroposterior length of the shaft and extends up approximately half the height (1); a deep, rugose fossa that occupies the entire anteroposterior length of the shaft and extends up approximately half the height (2).

Exemplars: BMRP 2002.4.1 (0), MOR 009 (1), FMNH PR2081 (2).

Phylogeny: Unmodified character 381 from Carr et al. (2017), aside from extra description that is specific to *T. rex*. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Appalachiosaurus*) and the adult condition corresponds to the state that is seen in *Bistahieversor* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from subtle to distinct.

185. Metatarsal II, lateral surface, shape, proximal view (Carr et al., 2017: character 382): small notch at midlength (0), notch extends from midlength to the posterior edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 382 from Carr et al. (2017), aside from description added to match what is exactly seen in *T. rex*. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Guanlong* to *Eotyrannus*) and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from limited to extensive.

Metatarsal III (1 character)

186. Metatarsal III, medial surface, form, anterior and posterior views (Carr et al., 2017: character 378): subtly convex (0), distinct medial expansion that forms a bulge along the distal part of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 378 from Carr et al. (2017); the straight condition is excluded since it is not seen in *T. rex*. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Kileskus* to *Eotyrannus*) and the adult condition corresponds to the state that is seen in *Appalachiosaurus* + Tyrannosauridae.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from subtle to distinct.

Metatarsal IV (2 characters)

187. Metatarsal IV, distal end, ratio of anteroposterior length to mediolateral width, distal view (Carr et al., 2017: character 383): wider mediolaterally than anteroposteriorly long (0), longer anteroposteriorly than mediolaterally wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 383 from Carr et al. (2017); polarity is reversed from its phylogenetic homologue. The juvenile condition corresponds to the state that is seen in Tyrannosauridae and the adult condition corresponds to the state that is seen in basal tyrannosauroids (*Yutyranus* to *Bistahieversor*).

Naïve hypothesis: Nonrecapitulatory character that is incongruent with the phylogenetic transition.

188. Metatarsal IV, lateral muscle attachment scar, form, plantar view (Carr et al., 2017: character 384): dorsoventrally tall and mediolaterally narrow (0); wide, oval, and coarse rugosity that covers more than half the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 384 from Carr et al. (2017), where the *absent* condition is excluded to reflect what is seen in *T. rex*. The juvenile condition corresponds to the state that is seen in basal tyrannosauroids (*Appalachiosaurus* to *Alioramus*) and the adult condition corresponds to the state that is seen in the *Daspletosaurus* + *Tyrannosaurus* clade.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from narrow to wide.

Pedal Phalanges (4 characters)

189. Digit I, phalanx 1, form, dorsal and ventral views (Carr et al., 2017: character 385): long and slender with a width to length ratio equal to or less than 26% (0), short and stout with a width to length ratio greater than 26% (1).

Exemplars: BMRP 2002.4.1 (0), TMP 1981.012.0001 (1).

Note: Each proximal phalanx is treated here separately to test the hypothesis of simultaneous change.

Phylogeny: Variant of character 385 from Carr et al. (2017), where the character is used for each proximal phalanx separately.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from slender to stout.

Result: Characters 189 to 192 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

190. Digit II, phalanx 1, form, dorsal and ventral views (Carr et al., 2017: character 385): long and slender with a width to length ratio less than or equal to 27% (0), short and wide with a width to length ratio greater than 27% (1).

Exemplars: BMRP 2002.4.1 (0), TMP 1981.012.0001 (1).

Phylogeny: Variant of character 385 from Carr et al. (2017), where the character is used for each proximal phalanx separately.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from slender to stout.

Result: Characters 189 to 192 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

191. Digit III, phalanx I, form, dorsal and ventral view (Carr et al., 2017: character 385): long and slender with a width to length ratio less than or equal to 27% (0), short and wide with a ratio greater than 27% (1).

Exemplars: BMRP 2002.4.1 (0), TMP 1981.012.0001 (1).

Phylogeny: Variant of character 385 from Carr et al. (2017), where the character is used for each proximal phalanx separately.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from slender to stout.

192. DIV, PH1, form, dorsal and ventral views (Carr et al., 2017: character 385): long and slender with a ratio of 34% or less (0); short and stout with a ratio greater than 34% (1).

Exemplars: BMRP 2002.4.1 (0), TMP 1981.012.0001 (1).

Phylogeny: Variant of character 385 from Carr et al. (2017), where the character is used for each proximal phalanx separately.

Naïve hypothesis: Recapitulatory character that is congruent with the phylogenetic transition from slender to stout.

Result: Characters 189 to 192 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

PHYLOGENETIC CHARACTERS (RAUHUT, 2003; 8 characters)

193. Snout, lateral sides, orientation, dorsal view (Rauhut, 2003: character 10): narrows as it extends rostrally (0), parallel-sided (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Phylogeny: Unmodified character 10 from Rauhut (2003).

194. Endocranium, size (Rauhut, 2003: character 63): large, REQ 37% 2.6 to 2.8 (0); small, REQ 37% 1.2 to 1.9 (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Note: REQ values are from Hurlburt et al. (2013), from Table 6.1, column “REQ 37%”. The 37% ratio of brain mass to endocast volume was selected arbitrarily, as the 50% ratio shows the same relative difference in magnitude of endocranium size.

Note: REQ is an abbreviation for Reptile Encephalization Quotient (Hurlburt et al., 2013).

Phylogeny: Variant of character 63 from Rauhut (2003); the polarity of this character is reversed from its phylogenetic homologue.

195. Palatine fenestra, size, ventral view (Rauhut, 2003: character 68): large (0), reduced or absent (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Phylogeny: Variant of character 68 from Rauhut (2003); the polarity of this character is reversed from its phylogenetic homologue.

196. Dentary, dentigerous region, form, dorsal view (Rauhut, 2003: character 76): straight (0), curves rostromedially to the symphysis (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

Phylogeny: Unmodified character 76 from Rauhut (2003).

197. Caudal vertebra 16, transverse process, form, dorsal view (Rauhut, 2003: character 118): absent or present as an indistinct triangular emargination along the ventrolateral edge of the pedicle (0), an anterolaterally extending and distinct process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 118 from Rauhut (2003); the polarity of this character is the reverse of its phylogenetic homologue.

198. Scapula, glenoid fossa, orientation, lateral view (Rauhut, 2003: character 135): extends anterodorsally ahead of the coracoid part (0), intermediate position (1), fossa faces posteriorly and does not extend ahead of the fossa on the coracoid (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), BMRP 2007.4.1 (1), FMNH PR2081 (2).

Phylogeny: Variant of character 135 from Rauhut (2003); polarity is reversed from that of its phylogenetic homologue.

199. Humerus, head, length to width ratio, proximal view (Rauhut, 2003: character 140): much wider than long (0), length approaches width (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 140 from Rauhut (2003).

200. Ilium, brevis fossa, medial and lateral sides, orientation, ventral view (Rauhut, 2003: character 176): parallel or subtly diverge from each other as they extend posteriorly (0), distinctly diverge from each other as they extend posteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Unmodified character 176 from Rauhut (2003) and of character 264 from Carrano et al. (2012).

PHYLOGENETIC CHARACTERS (CARRANO ET AL., 2012; 14 characters)

201. Maxilla, interdental plates, proximity to ventral alveolar margin, medial view (Carrano et al., 2012: character 20): closely approach where septa are one-third the depth of the plates (0), rostral plates are at least half their height above the ventral alveolar margin (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Phylogeny: Variant character 20 from Carrano et al. (2012), where relative height ratios are given here.

202. External mandibular fenestra, surangular, dorsal margin, form, lateral view (Carrano et al., 2012: character 118): a shallow notch (0), a deep notch with a steep caudodorsal orientation (1).

Exemplars: CMNH 7541 (0), MOR 008 (1).

Phylogeny: Variant of character 118 from Carrano et al. (2012), but the *moderate* state is not used here.

203. Maxilla, promaxillary fenestra, shape, caudolateral view (Carrano et al., 2012: character 28): mediolaterally narrow slit (0), round (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Phylogeny: Variant of character 28 of Carrano et al. (2012); shape is used here instead of size to reflect the differences seen in *T. rex*.

Ontogeny: First described by Carr (1999); transition from slit to foramen. Variant of ontogenetic character 32 of Carr and Williamson (2004).

204. Lacrimal, supraorbital process, caudal surface, joint surface above or lateral to that for the frontal, presence, caudal view (Carrano et al., 2012: character 62): absent (0), present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Phylogeny: Variant of character 62 from Carrano et al. (2012); differs from its phylogenetic homologue in treating the character states as *absence/presence*.

205. Palatine, dorsolateral ramus, subordinate processes, separation, lateral view (Carrano et al., 2012: character 111): dorsal and ventral processes not divergent, but parallel and separated by a narrow gap (0); widely divergent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: The point of reference in this character is the gap between the processes.

Phylogeny: Variant of character 111 of Carrano et al. (2012); the description (*tapered/expanded*) is altered to reflect the exact condition that is seen in *T. rex*.

206. Dentary, interdental plates, size, medial view (Carrano et al., 2012: 139): small triangular spikes (0), large (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

Phylogeny: Variant of character 139 from Carrano et al. (2012); polarity reversed.

207. Dentary, combined lengths of the first two alveoli, dorsal view (Carrano et al., 2012: 121): no longer than that of the third alveolus (0), greater than the length of the third alveolus (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 121 from Carrano et al. (2012), where the point of reference in both states is the third alveolus and the emphasis is given here to the first two alveoli, not the first three.

208. Dentary, caudal plate, caudal margin, margin of the external mandibular fenestra, depth, lateral view (Carrano et al., 2012: character 126): shallowly notched by the external mandibular fenestra (0), deeply notched by the fenestra to produce a long pair of caudal processes (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Phylogeny: Variant of character 126 from Carrano et al. (2012); polarity is reversed.

209. Premaxillary teeth, denticles, presence (Carrano et al., 2012: character 149): nondenticulate (0), denticulate (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Character 76 of Holtz (2001) and character 149 from Carrano et al. (2012); polarity is reversed from its phylogenetic homologue.

210. First maxillary tooth carinae, denticles, presence, mesial, distal, and lingual views (Carrano et al, 2012: character 146): both carinae are nondenticulate (0); mesial carina is denticulate only at midheight, the distal carina is denticulate (1); both carinae are denticulate to the apex (2). **ORDERED**

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1), FMNH PR2081 (2).

Phylogeny: Variant of character 146 from Carrano et al. (2012); polarity is reversed from its phylogenetic homologue.

211. Second maxillary tooth, mesial carina, denticles, presence (Carrano et al, 2012: character 146): mesial carina nondenticulate (0), denticulate (1).

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1).

Phylogeny: Variant of character 146 from Carrano et al. (2012); polarity is reversed from its phylogenetic homologue.

212. Axis, epiphysis+postzygapophysis complex, dorsoventral height, posterior view (Carrano et al., 2012: character 164): dorsoventrally shallow (0), dorsoventrally deep (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 164 from Carrano et al. (2012); dorsoventral height is emphasized here, instead of length, to reflect what is seen in *T. rex*.

213. Sacrum, spinous processes, mediolateral width relative to dorsal edge of ilium, dorsal view (Carrano et al., 2012: character 200): narrow, slightly wider than the ilium, marginally widens anteriorly and abruptly at its caudal end (0); several times wider than the dorsal edge of the ilium throughout, but same width at the middle (at SV3) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 200 from Carrano et al. (2012) where the point of reference is moved from the *remainder of spinous process* to the *dorsal edge of the ilium*.

214. Coracoid, origin for the biceps brachii, form, lateral view (Carrano et al., 2012: character 227): coarse fossa with a caudal lip (0), convexity (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Phylogeny: Variant of character 227 from Carrano et al. (2012); modified to reflect what is seen in *T. rex* (not a *tuber* or a *ridge* as is seen in other theropods), which changed the character from multistate to binary.

ONTOGENETIC CHARACTERS

BONY NARIS (1 character)

215. Skull, bony naris, dorsal margin, lateral view: premaxillary processes of the nasal are arched and curve rostroventrally, producing a dorsoventrally tall bony naris (0); the processes are straight and not arched, producing a dorsoventrally shallow bony naris (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

SUBNARIAL FORAMEN (1 character)

216. Subnarial foramen, fossa, extension onto premaxilla, external view: does not extend onto the premaxilla such that the entire margin of the foramen is a sharp edge (0), extends onto

the premaxilla such that the ventral half of the margin is excavated and only the dorsal half is a sharp edge (1), entire margin is rounded (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1), MOR 980 (2).

INCISIVE FORAMEN (1 character)

217. Incisive foramen, mediolateral and rostrocaudal positions, ventral view: caudal, where it is above the first three maxillary teeth and it occupies the midwidth between the alveolar region and midline of the palate (0); rostral, where it is at the premaxillomaxillary suture and close to the skull midline (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: The incisive foramen is the opening, in ventral view, which is enclosed between the intermaxillary process of the maxilla and the body of the premaxilla. It was first described, but not named, by Molnar (1990).

SNOUT (5 characters)

218. Snout, differentiation from orbitotemporal region, dorsal view: proximal end of the snout widens continuously into the orbitotemporal region (0), sharply differentiated at an angulation (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

219. Snout, dorsum, longitudinal bar formed by nasal and lacrimals, caudal end, width, dorsal view: mediolaterally narrow throughout (0), bar is greatly laterally expanded at the lacrimals (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: The presence of the expansion can be deduced from the width of an isolated lacrimal seen in dorsal view.

220. Snout, width, ventral view: continuously tapers in width rostrally (0), snout dilates such that the midregion is mediolaterally wider than the base of the snout (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

221. Snout, trough formed by the palatal process of the maxilla and palatine, caudal end, dorsal view: pinched off at the rostral end of the rostroventral ala of the lacrimal (0), pinched off ahead of the lacrimal by a short distance (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

Note: The point of pinch-out is marked by the joint surface of the palatine on the maxilla where it crosses the dorsum of the palatal process.

BONY PALATE AHEAD OF BONY CHOANAE (1 character)

222. Bony palate, extent, ventral view: between the mesial five maxillary teeth (0), between the mesial six maxillary teeth (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: This is equivalent to the position of the caudal end of the intermaxillary suture.

EXTERNAL ANTORBITAL FENESTRA (2 characters)

223. External antorbital fenestra, extent, lateral view: extends further rostr dorsally and caudodorsally, but limited caudoventrally (0); extends greatly caudoventrally, but limited rostr dorsally and caudodorsally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: In the subadult condition, the fenestra has a greater dorsal coverage of the side of the snout, whereas in the adult condition it has a greater caudoventral coverage of the snout.

224. External antorbital fenestra, ventral margin, transition to the subcutaneous surface, lateral view: entire ventral margin is deeply inset and separated from the subcutaneous surface by a crease (0), inset condition is reduced where the crease is limited caudally on the maxilla (1), the crease is eliminated and the depression extends ventrolaterally to the subcutaneous surface (2), the entire ventral surface is a wide and swollen shelf (3). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2), MOR 008 (3).

Note: In part, this character might be an epiphenomenon of tooth enlargement and so might covary with other characters that are influenced by tooth size.

INTERNAL ANTORBITAL FENESTRA (3 characters)

225. Internal antorbital fenestra, length to height ratio (Carr and Williamson, 2004: character 28): the fenestra is longer than tall (0), the fenestra is as tall as it is long (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: In part, this character might be an epiphenomenon of the increase in the height of the skull frame and so might covary with other characters influenced by increasing skull height.

Ontogeny: Variant of ontogenetic character 28 of Carr and Williamson (2004).

226. Internal antorbital fenestra, contribution made by the jugal, lateral view (Carr, 1999): excluded from the margin by the lacrimal and maxilla (0), limited contribution (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

BONY CHOANA (7 characters)

227. Bony choana, orientation of the openings of opposite sides relative to each other, dorsal and ventral views: openings face each other mediolaterally (0); choanae are not open to each other (i.e., they face medioventrally) (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

228. Bony choana, rostral end, position relative to medial interfenestral strut, ventral view: far rostral to the medial interfenestral strut (0), short distance ahead of the strut (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: The point of reference for the rostral limit of the bony choana is the joint surface for the vomer on the ventral surface of the palatal process of the maxilla.

Result: Characters 228 and 229 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

229. Bony choana, rostral end, position relative to teeth, ventral view: starts at the level of the sixth maxillary tooth (0), starts at the level of the eighth maxillary tooth (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: This character is included to test whether or not the position of the choana is independent of ontogenetic tooth loss.

Note: The point of reference for the rostral limit of the bony choana is the joint surface for the vomer on the ventral surface of the palatal process of the maxilla.

Result: Characters 228 and 229 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

230. Bony choana, exposure, lateral view: caudal end is marginally in view (0), caudal end is tall and widely exposed to view (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: The wide exposure seen in the subadult specimen CMNH 7541 is an artifact of dorsalward displacement of the palatines, which has brought their joint surfaces with the maxillae into view. Therefore, the opening was marginally exposed in the original, unaltered condition.

231. Bony choana, ventrolateral margin, contribution by the maxilla, dorsal view: extensive, more than half of the margin (0); limited contribution at its rostral end (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

232. Bony choana, caudal end, position relative to maxillary teeth, lateral and ventral views: at the level of the last tooth socket (0), ahead of the last tooth (1).

Note: The palatine in CMNH 7541 is displaced rostrally by 2.5 cm, which, when restored to its original position, places its caudal end above the caudal margin of the last tooth.

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

PALATINE FENESTRA (2 characters)

233. Palatine fenestra, rostrocaudal length, ventral view: rostrocaudally longer than mediolaterally wide (0), mediolaterally wider than rostrocaudally long (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

234. Palatine fenestra, rostral margin, form, ventral view: sharp angle (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

SUBORBITAL FENESTRA (1 character)

235. Suborbital fenestra, rostral half of the medial margin, ventral view: formed by the palatine, caudal half is formed by the pterygoid (0); margin is dominated by the pterygoid (1); entire medial margin is formed by the pterygoid (2). **ORDERED**

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

PALATE (1 character)

236. Palate, tallest point of the ventral surface, ventral view: at the caudal half of the internal antorbital fenestra (0), at the midlength or rostral half of the fenestra (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

POSTORBITAL BAR (4 characters)

237. Postorbital bar, composition, lateral view: the postorbital and jugal contribute equally (0), the postorbital is dominant (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

238. Postorbital bar, jugopostorbital suture, form, lateral view (Hurum and Sabath, 2003): curved line (0), distinctly bent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

239. Postorbital bar, postorbital margin of bar, orientation, lateral view: caudodorsal (0), vertical (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

240. Postorbital bar, plane change of the lateral surface from the cornual process of jugal to the postorbital, presence, rostral view: vanishingly subtle (0), distinct and twists the orbital region to face abruptly rostrolaterally (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

LATEROTEMPORAL FENESTRA (1 character)

241. Laterotemporal fenestra, gap between postorbital bar and squamosoquadratojugal bar, width, lateral view: gap is wide (0), gap is nearly closed (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

SECONDARY LATEROTEMPORAL FENESTRA (1 character)

242. Secondary laterotemporal fenestra between squamosal and quadratojugal, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

ADDUCTOR REGION (1 character)

243. Adductor region, rostral limit, caudal and ventral views: a short distance caudal to the level of the midlength of the orbital fenestra (0), caudal to the level of the orbital fenestra (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: The rostral limit is marked by the rostrocaudal position of the caudal margin of the jugal process of the ectopterygoid.

DORSOTEMPORAL FOSSA (1 character)

244. Dorsotemporal fossa of the postorbital, orientation, caudal view: faces dorsally and is horizontally oriented (0), faces caudodorsally and tilts medioventrally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

PARAQUADRATE FORAMEN (1 character)

245. Paraquadrate foramen, mediolateral position, caudal view: positioned toward the lateral side of the quadratojugoquadrate complex (0), positioned at the midwidth of the complex (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

FOSSA FOR THE VENTRAL PTERYGOID MUSCLE (1 character)

246. Fossa for the ventral pterygoid muscle, rostrrodorsal margin on the surangular, distinctiveness, lateral view: indistinct but traceable, bounded dorsally on the dentary by ridges

(0); distinct and most deeply inset on the dentary where its dorsal edge is defined by a ridge (1); obscured by the convex surface of the mandibular ramus (2).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

FORAMEN MAGNUM (1 character)

247. Foramen magnum, size relative to the occipital condyle, caudal view (Currie, 2003): large (0), small (1).

Exemplars: CMNH 7541 (0), RSM 2523.8 (1).

Note: The *large* condition corresponds to a foramen that is at least half the width of the occipital condyle, whereas the *small* condition corresponds to a foramen that is less than half the width of the occipital condyle.

INTERNAL MANDIBULAR FENESTRA (1 character)

248. Internal mandibular fenestra, caudal margin, medial view: not sinuous (0), subtly sinuous (1), deeply sinuous (2). **ORDERED**

Exemplars: CMNH 7541 (0), UWBM 99000 (1), AMNH FARB 5027 (2).

APERTURE OF THE MECKELIAN FOSSA (1 character)

249. Aperture of the Meckelian fossa, shape, medial view: lens-like where it tapers rostrally and caudally (0), teardrop-like where it is tallest rostrally and tapers to a point caudodorsally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

NASOLACRIMAL JOINT (1 character)

250. Nasolacrimal joint surface, form, lateral, ventral, and dorsal views: tongue-in-groove (0), peg-in-socket (1).

Exemplars: FMNH PR2411 (0), MOR 555 (1).

LACRIMOPREFRONTAL JOINT (1 character)

251. Lacrimoprefrontal joint surface, caudal and medial views: abutting (0), peg-in-socket.

Exemplars: FMNH PR2411 (0), CM 9380 (1).

PREMAXILLA (35 characters)

252. Premaxilla, snout tip, width, dorsal view: narrow, where the bones meet at a low angle, closer to 90 degrees than to 180 degrees (0); wide, closer to 180 degrees than to 90 degrees (1).

Exemplars: CMNH 7541 (0), LACM 23844 (1).

Note: In *T. rex* the rostral end of the snout widens with growth, which increases the angle (as seen in dorsal or ventral view) formed between the rostral surfaces of the complementary premaxillae. When viewed from the front, the premaxillae in subadults converge toward each other at the midline along a distinct angle relative to each other, whereas in adults the bones converge at an indistinct angle such that the bones together are oriented in nearly the same vertical mediolateral plane. This character serves as a proxy for an increase in snout width.

Phylogeny: This character might be equivalent to character 15 of Carr et al. (2017), but it is included here to test that hypothesis.

Result: Character 319 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

253. Premaxilla, body of the bone, lateral margin of bone, from the midheight of the subnarial foramen ventrally, rostral view (Carr and Williamson, 2004: character 2): concave (0), straight or convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Ontogeny 1: First described in Carr (1999) as a transition from concave to straight.

Ontogeny 2: Variant of ontogenetic character 2 from Carr and Williamson (2004).

254. Premaxilla, body of the bone, rostral margin, position of change from rostradorsal to caudodorsal, lateral view (Carr, 1999): below the level of ventral margin of the bony naris (0), at or above the level of the ventral margin of the bony naris (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

255. Premaxilla, body of the bone, alveolar region, dorsoventral height, external view (Carr, 1999; Brochu, 2003; Carr and Williamson, 2004: character 3): shallow, where the subnarial foramen is closer to the alveolar margin than to its dorsal margin (0); deep, where it is closer to the dorsal margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: This character is equivalent to the dorsoventral height of the lateral alveolar process (region below the narial fossa), as indicated by the dorsal extent of the subcutaneous surface, which corresponds to the position of the ventral margin of the subnarial foramen.

Ontogeny: First described in Carr (1999); transition from shallow to deep. Variant of ontogenetic character 3 from Carr and Williamson (2004).

256. Premaxilla, body of the bone, size of marginal foramina and depth of their sulci, lateral and rostral views: small and shallow (0), large and deep (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

257. Premaxilla, body of the bone, subcutaneous texture, degree of texture, external view: surface is irregular, but not rugose (0); rugose (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

258. Premaxilla, body of the bone, subcutaneous surface, orientation to the maxillary buttress, rostral view: surface extends directly caudally to the buttress without flaring laterally (0); surface extends laterally at the buttress, flaring laterally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

259. Premaxilla, narial fossa, ventral margin, orientation, rostral view: dorsomedial to ventrolateral, to ventral edge of the subnarial foramen (0); ventrolateral to dorsolateral to the ventral edge of the foramen (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

260. Premaxilla, nasal process, rostral margin, orientation, lateral and medial views: rostral margin of base nearly vertical (0), extends rostradorsally (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

261. Premaxilla, nasal process, mediolateral width, rostral view: mediolaterally narrower than long and ‘pinched’ along the ventral half (0); columnar uniformly (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

262. Premaxilla, nasal process, length of the lateral joint surface for the nasal, lateral view: extends rostrally halfway or less along the process (0), extends rostrally past the halfway point (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

263. Premaxilla, nasal process, v-shaped foramen at base, rostrocaudal position, lateral view: closest to the rostral margin of the bone (0), at the midlength of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

264. Premaxilla, maxillary process, width, dorsal view (Carr, 1999; Carr and Williamson, 2004: character 4): narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Ontogeny: First described in Carr (1999); transition from narrow to wide. Variant of ontogenetic character 4 from Carr and Williamson (2004).

265. Premaxilla, maxillary process, length, lateral and dorsal views (Carr, 1999): short, does not approach the caudal margin of the bony naris (0); long, approaches the caudal margin of the bony naris (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Ontogeny: The adult state of this character was first described in Carr (1999) for *D. torosus* and *T. rex*.

266. Premaxilla, maxillary process, notch in medial margin of the base of the maxillary process, dorsal view: shallow (0), deep (1).

Note: The *notch* is the medial margin of the proximal (=rostral) end of the process that abruptly extends medially to the symphyseal region and groove that is situated above the palatal process; distally (=caudally) the caudal end of notch is marked by an angulation from which the process tapers rapidly.

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

267. Premaxilla, maxillary process, direction, rostradorsal view: process as a whole extends caudolaterally from a subtle angulation at the subnarial foramen (0), process as a whole extends caudomedially from a distinct angulation at the subnarial foramen (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

268. Premaxilla, maxillary process, ridge along medial edge, caudal view: ridge is present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

269. Premaxilla, maxillary process, pegs on ventral surface, presence, caudal view: absent (0); low, coarse pegs are present, where one is toward the rostralateral edge and the other is toward the caudomedial edge of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

270. Premaxilla, maxillary process, base, dorsum, form, lateral and dorsal views: convex (0), concave (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

271. Premaxilla, maxillary process, dorsum, dorsal view: dorsum is gently convex in transverse section (0), lateral region is modified into a wide strut that extends to the caudal tip of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

272. Premaxilla, maxillary process, joint surface for the maxilla and nasal, exposure, lateral view: joint surface is not exposed in lateral view (0), joint surface is exposed to view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

273. Premaxilla, maxillary process, medial margin above foramen-penetrated groove and palatal process, groove, presence, medial view: absent (0); groove cuts across the medial edge of the process from the ventral surface of the process to the dorsal surface of the process, where it rapidly fades (1).

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1).

274. Premaxilla, maxillary process, lateral margin above the subnarial foramen, form, dorsal view: concave (0), convex (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

275. Premaxilla, alveolar skirts, presence, external view (Carr, 1999): absent (0), present (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

Ontogeny: First described in Carr (1999); transition from absent to present.

276. Premaxilla, interpremaxillary suture, texture, rostral and medial views: smooth (0), coarse (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

277. Premaxilla, interpremaxillary suture, caudal margin, distinctiveness, medial view: caudal margin is not distinct (0), raised into coarse dorsal and ventral joint surfaces (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

278. Premaxilla, interdental plates, width, medial view: all are narrow (0), all are wide except the first or all are wide (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

279. Premaxilla, interdental plates, fusion, medial view: plates are not fused together (0), plates are fused (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

280. Premaxilla, interdental plates, separation, medial view: plates are completely separated from each other by narrow slots (0); separated by deep triangular notches (1); ventral edge of fused plates are irregular and distinct notches are absent (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 980 (2).

281. Premaxilla, foramen between interdental plates 3 and 4, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

282. Premaxilla, foramen between all interdental plates, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

283. Premaxilla, palatal process, caudoventral process, size, medial view: small (0), massive (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

284. Premaxilla, palatal process, groove dorsal to the process, rostrocaudal length, medial view: long, extends rostral to the caudoventral process (0); short, shorter than the caudoventral process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

285. Premaxilla, symphyseal surface, caudal margin, orientation, medial view: vertical (0), caudodorsal (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

286. Premaxilla, medial alveolar process, texture, medial view: smooth (0), coarse (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

287. Premaxilla, lateral alveolar process, ventral margin on either side of the interpremaxillary suture, orientation, rostral view: horizontal (0), extends medioventrally (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

288. Premaxilla, maxillary buttress, joint surface for the maxilla, orientation, lateral view: faces directly caudally (0), faces caudolaterally and so extends into view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

289. Premaxilla, maxillary buttress, mediolateral width, caudal view (Carr, 1999): narrow (0), wide (1).

Note: The relative width of the joint surface can be deduced in articulated skulls when seen in ventral view.

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Ontogeny: The narrow juvenile state was first described in Carr (1999).

NASAL (39 characters)

290. Nasal, dorsoventral depth of bone, lateral view (Carr, 1999; Carr and Williamson, 2004: character 10): shallow (0), deep (1).

Exemplars: LACM 28471 (0), RSM 2523.8 (1).

Note: This character is qualitatively assessed by comparing the dorsoventral height of the frontal ramus in lateral view.

Ontogeny: First described in Carr (1999); transition from light to thick. Variant of ontogenetic character 10 from Carr and Williamson (2004).

291. Nasal, tallest point of bone, lateral view: rostral, where it is caudal to and along the premaxillary process (0); caudal, where it is above the maxillary flange and caudal to the bony naris (1).

Exemplars: LACM 28471 (0), MOR 555 (1).

292. Nasal, rostral region, width and height, dorsal and lateral views (Carr, 1999): narrow and convex (0), wide and low (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

Ontogeny: First described in Carr (1999); transition from strongly vaulted to moderate.

293. Nasal, cross-section of rostral third, rostral and dorsal views (Carr and Williamson, 2004: character 11): angular (0), convex (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Note: *Angular* refers to the condition where the lateral surface of each bone is flat and extends dorsomedially to the convex dorsum of the conjoined bones.

Ontogeny: Variant of ontogenetic character 11 from Carr and Williamson (2004).

294. Nasal, rostral region, ventral view: bone is nearly flat across the internasal suture (0), apposed bones extend ventrally to form a midline ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

295. Nasal, rostromedial ridge, presence, dorsal and lateral views: absent (0), ridge that extends rostroventrally toward the caudal or caudodorsal margin of the margin of the bony naris is present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: In some adults (MOR 555) this ridge defines the caudolateral margin of the fossa that covers the conjoined nasal processes.

296. Nasal, midline bumps, number, dorsal view: absent (0), less than six (1), six or greater than six (2). **ORDERED**

Exemplars: LACM 28471 (0), CMNH 7541 (1), BMRP 2002.4.1 (2).

297. Nasal, razor ridge, position, dorsal view: at proximal end of rostral internasal suture (0), distal to proximal end of suture (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: The term *razor ridge* refers the sharp, dorsally extending ridge that is formed by the abutting nasals at the proximal end of the rostral internasal suture.

298. Nasal, midline ridge that extends ahead of the frontal ramus, length, dorsal view: stops above the maxillary flange or above the rostral half of the internal antorbital fenestra (0), stops short of the maxillary flange or a short distance ahead of the caudolateral process (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

299. Nasal, dorsal neurovascular foramina, number of rows, dorsal view: one row (0), two (1), three (2). **ORDERED**

Exemplars: LACM 28471 (0), CMNH 7541 (1), BMRP 2002.4.1 (2).

300. Nasal, premaxillary processes, length and width, dorsal view: short and wide (0), long and narrow (1).

Exemplars: CMNH 7541 (0), LACM 23845 (1).

301. Nasal, lateral margin of premaxillary process, form, dorsal view (Carr and Williamson, 2004: character 7): convex (0); gently convex, straight to concave, sinuous (1).

Exemplars: CMNH 7541 (0), LACM 23845 (1).

Ontogeny: Variant of ontogenetic character 7 from Carr and Williamson (2004).

302. Nasal, premaxillary processes, orientation, lateral view: extend rostr dorsally (0); extend horizontally to rostroventrally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

303. Nasal, ventral joint surface for the medial process of the lacrimal and maxilla, connection, ventral view: slots for the medial process of the lacrimal and the maxilla are not continuous (0), slots are continuous (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

304. Nasal, ventral row of neurovascular foramina, mediolateral position, ventral view: close to the lateral edge of the bone at its rostral and caudal ends, but at the midwidth at its midlength (0); entire row is close to the lateral edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

305. Nasal, lateroventral margin rostral to the joint surface for the frontal, direction, ventral view: rostromedial (0), rostrolateral (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: This margin is defined by the lateral edge of the bone.

306. Nasal, joint surface for the medial process of the lacrimal, form, ventral view: concave (rostromedially-extending) in ventral view (0), complementary joint surfaces are parallel or convex (rostrolaterally-extending) (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1).

307. Nasal, joint surface for the lacrimal, medial wall of ventral slot that is adjacent to the caudolateral process and rostrally, exposure, lateral view: extends ventrally into view below the external surface of the bone (0), is hidden from view by the external surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

308. Nasal, joint surface for the lacrimal, part that extends caudodorsally from the caudolateral process, texture, lateral view: smooth, where it is flat or concave in vertical section (0); coarse (1).

Exemplars: BMRP 2002.4.1 (0), MOR 2822 (1).

309. Nasal, joint surface for the lacrimal, region that extends caudodorsally from the caudolateral process, size, lateral and ventral views: short flange (0), long and deep flange (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

310. Nasal, joint surface for the lacrimal, region that extends caudodorsally from the caudolateral process, stops caudally as a discrete but stout process at the dorsolateral edge of the frontal ramus, dorsal and lateral views: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

311. Nasal, caudolateral process, rostrocaudal length, lateral view (Carr, 1999): short, where its length is not as tall as the height of the nasal ahead of it (0); long, where it is as tall or taller than the height of the nasal ahead of it (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Ontogeny: This character was first described in Carr (1999) for *D. torosus* and *T. rex*.

312. Nasal, caudolateral process, dorsoventral height, lateral view: shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: In the *shallow* condition, the process is uniformly shallow and only slightly tapers caudally; in the *deep* condition, the process tapers distinctly as it extends caudally.

313. Nasal, frontal ramus, mediolateral width caudal to lacrimal overlap, dorsal view (Russell, 1970): wide (0), narrow (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note 1: As used here, the *frontal ramus* is the region from the rostral tip of the joint surface for the lacrimal, as seen in dorsal view, to the caudal extremity of the bone.

Note 2: In the *narrow* condition, the ramus tapers (i.e., reduces in width) as it extends caudally, whereas in the *wide* condition it maintains a constant width or widens as it extends caudally.

314. Nasal, frontal ramus, dorsal surface, tilt, dorsal and caudal views (Carr, 1999): level (0), tilts medioventrally (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Ontogeny: This character was first described in Carr (1999) for *D. torosus*.

315. Nasal, frontal ramus, dorsum, cross section, dorsal view: flat (0), subtly or greatly convex (1).

Note: As used here, the dorsum only refers to the smooth dorsal surface of the ramus, excluding the coarse subcutaneous surface that tapers caudally along the dorsolateral edge of the ramus.

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1).

316. Nasal, frontal ramus, notch for dorsolateral edge of lacrimal, presence, dorsal view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1).

Note: If the nasal is missing, the corresponding notch is seen in the lacrimal.

317. Nasal, frontal ramus, midline septum, depth, ventral view: a vanishingly shallow ridge that fades rostrally (0), a deep ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

318. Nasal, frontal ramus, joint surface for the frontal, width and orientation, ventral view: wide caudally and tapers rostromedially (0), wide throughout and does not taper along its rostral half (1).

Exemplars: LACM 28471 (0), RSM 2523.8 (1).

319. Nasal, caudal internasal suture, rostral extent, dorsal view: far caudal to the caudolateral process (0), reaches the level of the caudolateral process (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8.

Note: This character was included to test the hypothesis that the length of suture decreases with ontogeny, as hypothesized by Lü et al. (2014).

Result: Characters 319 and 320 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

320. Nasal, caudal internasal suture, rostral extent, ventral view: closes a short distance ahead of the joint surface for the frontal and does not reach the region of the lacrimal slot; i.e. stops far short of the caudolateral process (0); extends far rostral to the joint surface for the frontal to where the lacrimal produces a deep ventrolateral slot in the nasal; i.e., closely approaches the caudolateral process (1).

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1).

Note: This character was included to test the hypothesis that the length of suture decreases with ontogeny, as hypothesized by Lü et al. (2014).

Result: Characters 319 and 320 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

321. Nasal, lateral frontal process, constriction, dorsal view: not constricted (0); pinched into a narrow process (1); pinched out of existence (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1), MOR 980 (2).

322. Nasal, lateral frontal process, coverage by lacrimal, dorsal view: not covered by the lacrimal (0), covered by the lacrimal (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

323. Nasal, medial frontal process, exposure, dorsal view: exposed (0), concealed (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: in the *concealed* condition, the medial processes are pinched between the nasal processes of the frontal such that they take on a vertical orientation and so are not seen as forming a wide wedge that separates the tips of the frontals.

324. Nasal, medial frontal process, size, dorsal view (Carr, 1999): smaller than the lateral frontal process (0), as large as the lateral frontal process (1).

Exemplars: BMRP 2002.4.1 (0), TMP 1981.006.0001 (1).

Ontogeny: First described in Carr (1999); transition from absent to present.

MAXILLA (103 characters)

325. Maxilla, shape, lateral view (Carr, 1999): triangular in outline and dorsoventrally shallow (0), dorsoventrally tall (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: This qualitative character takes into account the dorsoventral height of the horizontal ramus, the caudodorsal angle of the ascending ramus, and the contour of the rostral margin of the internal antorbital fenestra. In the *shallow* condition the horizontal ramus is dorsoventrally shallow, the ascending ramus extends at a low caudodorsal angle, and the rostral margin of the fenestra is acute. In the *tall* condition, the horizontal ramus is deep, the ramus extends at a steep caudodorsal angle, and the rostral margin of the fenestra is obtuse.

Ontogeny: Variant of character first described in Carr (1999); transition from long internal antorbital fenestra to round fenestra.

326. Maxilla, rostradorsal margin, angle, lateral view: low angle (0), steep angle that gives the bone a truncated appearance (1), steep angle that results from dorsoventral expansion of the bone (2).

Exemplars: LACM 28471 (0), CMNH 7541 (1), CM 9380 (2).

327. Maxilla, mediolateral width, all views (Carr, 1999; Carr and Williamson, 2004: character 14): narrow and laterally flat (0), wide and laterally convex (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); transition from transversely compressed to thick. Variant of ontogenetic character 14 from Carr and Williamson (2004).

328. Maxilla, region of the subnarial foramen and premaxillary buttress, orientation, lateral view: slopes rostroventrally (0), extends along a steep rostroventral angle or vertical (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

329. Maxilla, premaxillary buttress, dorsoventral depth, lateral and rostral views: marginally deeper or shallower than the subnarial foramen (0), deeper than the subnarial foramen (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Note: This character is included to test if it covaries with the relative dorsoventral position of the subnarial foramen.

Result: Character 329 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

330. Maxilla, subnarial foramen, depth into rostral margin of the maxilla, lateral view: shallow concavity (0), deep notch (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

331. Maxilla, tract of the subnarial foramen, number of foramina, lateral and rostral views: one (0), two (1).

Exemplars: CMNH 7541 (0) BMRP 2002.4.1 (1).

332. Maxilla, tract of the subnarial foramen, rostradorsal foramen, presence, rostromedial view: absent (0), present (1).

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1).

Note: This character is included to identify the sequence of appearance of the foramina.

333. Maxilla, tract of the subnarial foramen, rostroventral foramen, presence, rostromedial view: present (0), absent (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Note: This character is included to identify the sequence of disappearance of the foramen.

334. Maxilla, subnarial fossa, lateral margin, ridge, form, lateral and rostromedial views: fossa is bounded by a prominent and sharp ridge (0), ridge is low and indistinct or absent (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

335. Maxilla, narial fossa, extent, lateral and rostral views: does not depress the region caudal to the subnarial foramen (0), depresses the region (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

336. Maxilla, region rostradorsal to the external antorbital fenestra, expansion, lateral view (Carr, 1999; Carr and Williamson, 2004: character 33): not expanded (0), expanded (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Note: This also includes the region above the maxillary fenestra.

Ontogeny: First described in Carr (1999); transition from shallow to expanded. Variant of ontogenetic character 33 from Carr and Williamson (2004).

337. Maxilla, lateral surface, region ahead of the maxillary flange, form, lateral view: concave (0), convex (1).

Exemplars: RSM 2347.1 (0), AMNH FARB 5027 (1).

338. Maxilla, horizontal ramus, form, ventral view: weakly sinusoidal where the caudal 3/4 is concave or straight (0); lateral surface is convex and curves caudomedially to the base of the jugal ramus, which extends abruptly caudolaterally (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

339. Maxilla, horizontal ramus, dorsoventral depth, lateral view (Carr, 1999; Carr and Williamson, 2004: character 21): shallow, ratio of its maximum height (at the rostral margin of the external antorbital fenestra) to the length of the tooth row is less than 26% (0); deep, the ratio is greater than 26% (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Note: For incomplete specimens, where the tooth row cannot be measured, the height of the ramus can be compared with that of the antorbital fossa that extends below the internal antorbital fenestra; where the ramus exceeds the fossa in height, it corresponds to the deep condition.

Ontogeny: First described in Carr (1999); transition from shallow to deep. Variant of ontogenetic character 21 from Carr and Williamson (2004).

340. Maxilla, horizontal ramus, form below internal antorbital fenestra, lateral view:

dorsoventrally the shallowest part of the ramus in that it has the appearance of a distinct ‘waist’ (0), ramus is tall and a biconcave waist is absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

341. Maxilla, intermaxillary process, length of joint surface, medial view: stops ahead of the strut that separates the promaxillary sinus from the maxillary antrum (0); extends caudal to the strut, reaching the level of the promaxillary fenestra (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

342. Maxilla, intermaxillary process, joint surface, width, ventral view: confluent with medial surface such that the process has a uniform width (0), caudal end extends medially and widens the rostral end of the palatal process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

343. Maxilla, intermaxillary process, dorsoventral position of the base, medial view: a short distance above the medial alveolar margin (0), a great distance above the medial alveolar margin (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

344. Maxilla, intermaxillary process, position of distal end, medial view: extends below the level of the medial alveolar margin (0), stops a short distance above the medial alveolar margin (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

345. Maxilla, intermaxillary process, ventral surface of base, orientation, medial view: extends medially or at a low dorsomedial angle, ventral surface is not maximally exposed (0); extends mediodorsally at a steep angle, exposing the ventral surface (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

346. Maxilla, rostroventrally extending groove between the joint surface of the intermaxillary process and that of the palatal process, medial view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

347. Maxilla, subcutaneous surface of the ascending ramus, extent, lateral view: does not reach the level of the rostral margin of the internal antorbital fenestra (0), reaches or extends caudal to the rostral margin of the fenestra (1).

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1).

348. Maxilla, subcutaneous surface above the interfenestral strut, dorsoventral depth, lateral view (Carr, 1999): shallow (0), deep (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from shallow to expanded.

349. Maxilla, external antorbital fenestra, rostradorsal margin, distance from maxillonasal suture, lateral view (Carr, 1999): closely approaches (0), widely separated (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from shallow to expanded.

350. Maxilla, ascending ramus, dorsal and ventral margins, lateral view: parallel (0), converge (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Note: This excludes the joint surface for the nasal so that articulated skulls can be scored.

351. Maxilla, ascending ramus, orientation and form, lateral view: flat and faces laterally (0); gently convex in vertical section and extends steeply ventromedially (more ventral than medial (1); as for state (1), but ‘twisted’, where a shallow groove extends caudodorsally across the ramus (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

352. Maxilla, ascending ramus, joint surface for the rostroventral process of the lacrimal, depth, lateral view: shallow groove (0), deep slot (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

353. Maxilla, ascending ramus, joint surface for the lacrimal, depth, medial view: shallow groove (0), intermediate (1), deep slot (2). **ORDERED**

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1), MOR 1125 (2).

354. Maxilla, rostradorsal margin between maxillary flange and joint surface for the premaxilla, form, lateral view: concave to straight (0), convex (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

355. Maxilla, joint surface for the nasal, rostral end, position on dorsolateral surface, lateral view (Carr, 1999; Carr and Williamson, 2004: character 15): extends into lateral view (0), blocked from view by the subcutaneous surface (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from dorsolateral to dorsal (*A. libratus*), or, dorsal to dorsomedial (*T. rex*). Variant of ontogenetic character 15 from Carr and Williamson (2004).

356. Maxilla, lateral surface of the interfenestral strut, dorsal end, form, lateral view (Carr and Williamson, 2004: character 18): fossa absent (0), fossa present (1), perforated (2).

ORDERED

Exemplars: RSM 2347.1 (0), AMNH FARB 5027 (1), CM 9380 (2).

Ontogeny: Variant of ontogenetic character 18 from Carr and Williamson (2004).

357. Maxilla, vestibular bulla, lateral and dorsal views (Carr, 1999; Carr and Williamson, 2004: character 20): flat or convex (0), swollen (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus* and *D. torosus*. Variant of ontogenetic character 20 from Carr and Williamson (2004).

358. Maxilla, alveolar process, subcutaneous surface, orientation to the ventral margin of the tooth row, lateral view: flat (0), extends medioventrally along the marginal row of foramina (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

359. Maxilla, alveolar process, alveolar skirts, presence, lateral view: absent (0), present (1).

Exemplars: LACM 28471 (0), MOR 980 (1).

Ontogeny: This character was first described in Carr (1999).

360. Maxilla, alveolar process, ventral margin, angulation, lateral view: an angulation between the rostral and caudal regions of the tooth row margin is absent (0); angulation is present such that the caudal end of the margin extends abruptly caudodorsally, but it is subtle (1), angulation is distinct (2). **ORDERED**

Exemplars: RSM 2347.1 (0), TMP 1981.006.0001 (1), CM 9380 (2).

361. Maxilla, promaxillary fenestra, caudomedial edge, proximity to maxillary fenestra, lateral view: edge is not formed by the maxillary fenestra (0), edge is formed by the maxillary fenestra (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

362. Maxilla, promaxillary fenestra, orientation, medial view: opens medially into the promaxillary sinus as a rostromedially-directed foramen (0), opens rostrally into the promaxillary sinus (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

363. Maxilla, promaxillary fenestra, lateral and medial margins, orientation, caudal view: converge above the promaxillary fenestra (0), converge at the dorsal margin of the maxillary fenestra (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

364. Maxilla, promaxillary sinus, rostral extent, medial view: reaches the septum between alveoli 2 and 3 (0), extends above the first alveolus (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

365. Maxilla, promaxillary sinus, caudodorsal extent, medial view (Molnar, 1991): does not extend past the transverse strut separating it from the maxillary antrum (0), extends caudodorsally past the strut into the ascending ramus (1).

Exemplars: RSM 2347.1 (0), MOR 555 (1).

366. Maxilla, promaxillary sinus, number of dorsal recesses, medial view (Molnar, 1991): two (0), three or four (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

367. Maxilla, promaxillary sinus, dorsoventral depth of region, medial view: shallow where the tooth root bulges fill the floor of the sinus (0), deep where the sinus is basin-like and the tooth root bulges do not fill the space (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

368. Maxilla, promaxillary sinus, sinus floor, depth, mediodorsal view: not deepened by a recess (0), deepened by a pair of recesses (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

369. Maxilla, promaxillary sinus, sinus floor, strut, presence and direction, mediodorsal view: strut absent (0), present and extends rostromedially (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

370. Maxilla, maxillary fenestra, rostradorsal margin, position, lateral view (Carr, 1999; Carr and Williamson, 2004: character 22): does not approach the rostral margin of the antorbital fossa (0), approaches the margin (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from circular to elongate. Variant of ontogenetic character 22 from Carr and Williamson (2004).

371. Maxilla, maxillary fenestra, shape of the caudodorsal margin of the maxillary fenestra, lateral view: convex (0), straight or concave (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

372. Maxilla, maxillary fenestra, ventral margin, presence, lateral view: present as a distinct, longitudinal ridge (0), obliterated and incorporated into the shelf-like antorbital fossa (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

373. Maxilla, antorbital fossa, rostroventral corner, distinctiveness, lateral view (Carr, 1999; Carr and Williamson, 2004: character 16): distinct (0), indistinct and grades into the subcutaneous surface (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); transition from distinct to grades. Variant of ontogenetic character 16 from Carr and Williamson (2004).

374. Maxilla, antorbital fossa, depth relative to subcutaneous surface, lateral view: shallowly inset (0), fossa is deeply inset owing to a strut that extends along the rostral and rostradorsal margin of the external antorbital fenestra (1), depth is reduced along the dorsal margin of the fenestra (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

375. Maxilla, antorbital fossa, position of region of greatest inset depth, lateral view: along the rostral margin of the external antorbital fenestra (0), along the rostradorsal margin of the external antorbital fenestra (1), below interfenestral strut (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 555 (2).

376. Maxilla, antorbital fossa, mediolateral width, below the maxillary fenestra and internal antorbital fenestra, lateral view (Carr, 1999): shallow (0), deep (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Ontogeny: The adult state of this character was first described in Carr (1999) for *D. torosus*.

377. Maxilla, antorbital fossa, presence of accessory recesses, lateral view (Carr and Williamson, 2004: character 24): absent (0), present (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Note: As used here, “recesses” refers to deep, sharp-edged fossae or penetrating holes.

Ontogeny: Variant of ontogenetic character 24 from Carr and Williamson (2004).

378. Maxilla, antorbital fossa, lateromedially penetrating foramina, presence, lateral and medial views: absent (0), present (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

379. Maxilla, antorbital fossa, height below the internal antorbital fenestra, lateral view: reduces in height as it extends caudally to the jugal (0), uniform height to the jugal (1).

Exemplars: RSM 2347.1 (0), CMNH 7541 (1).

380. Maxilla, antorbital fossa, region below the internal antorbital fenestra, form, lateral view: separated by a deep crease from the subcutaneous surface (0), inset condition is reduced such that the crease is limited caudally toward the jugal (1), crease is absent (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), AMNH FARB 5027 (2).

381. Maxilla, maxillary antrum, base of medial surface of lateral interfenestral strut, medial view (Carr, 1999): flat (fossa absent) (0), shallow fossa (1), deep fossa present that may penetrate externally (2). **ORDERED**

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Ontogeny: This character was first described in Carr (1999) for *D. torosus*.

382. Maxilla, maxillary antrum, region above medial foramen into antrum, medial view: region is imperforate (0); perforated by a large foramen, creating a dorsal opening into the antrum (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

383. Maxilla, maxillary antrum, dorsal margin, orientation, medial view (Carr, 1999): rostroventral (0), horizontal in part or completely (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus* and *D. torosus*.

384. Maxilla, maxillary antrum, epiantral recess, dorsal extent, medial view: does not undercut the dorsal margin of the antrum (0), undercuts the dorsal margin (1).

Exemplars: RSM 2347.1 (0), MOR 980 (1).

385. Maxilla, lateral interfenestral strut, dorsal end, fossa, medial view: fossa is bounded rostrally by a very low ridge or a ridge is absent (0), bounded by a distinct ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

386. Maxilla, medial interfenestral strut, form, medial view: wide, stout, extends caudodorsally (0); tall, thin, extends caudodorsally or rostradorsally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

387. Maxilla, medial interfenestral strut, rostrocaudal position, medial view: at caudal half of base of the lateral interfenestral strut (0), at midlength of base of the lateral strut (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

388. Maxilla, medial interfenestral strut, position of dorsal half relative to the rostral margin of the antorbital fenestra, lateral view: caudal to margin of fenestra, where it is visible in lateral view (0); rostral to margin of fenestra, where it is not visible laterally (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

389. Maxilla, maxillary sinus system, width, dorsal view (Carr, 1999): promaxillary sinus, maxillary antrum, and palatal shelf extend only a few mm medial to the tooth root bulges (0); extend far medial to bulges, doubling bone width (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: Coding for FMNH PR2081 is based on the ventral view of the palate, where it is obvious that the palatal shelf is mediolaterally wide in this view.

Ontogeny: This character was first described in Carr (1999) for *D. torosus*.

390. Maxilla, subcutaneous surface, extent at the rostral end of the joint surface for the jugal, lateral and dorsal views: does not extend between the joint surface and the antorbital fossa (0); extended medially, separates the rostral end of the joint surface from the antorbital fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

391. Maxilla, marginal alveolar foramina, size, lateral view (Carr and Williamson, 2004: character 26): small (0), large (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Ontogeny: Variant of ontogenetic character 26 from Carr and Williamson (2004).

392. Maxilla, caudal-most alveolar foramen, dorsoventral position, lateral view: at or above midheight of the ventral jugal process (0), below midheight (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

393. Maxilla, sulcus of the caudal-most alveolar foramen, breach of ventral margin, lateral view (Carr, 1999; Carr and Williamson, 2004: character 27): does not breach the ventral margin of the jugal process (0), breaches the ventral margin (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); transition from above ventral margin of bone to breaches though ventral margin. Variant of ontogenetic character 27 from Carr and Williamson (2004).

394. Maxilla, internal antorbital fenestra, shape of the rostral margin, lateral view (Carr, 1999): acute (0), obtuse curve (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from long internal antorbital fenestra to round fenestra.

395. Maxilla, internal antorbital fenestra, point of rostralmost incursion, relative to the maxillary fenestra, lateral view: below midheight of the maxillary fenestra (0), at midheight of the fenestra or higher (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

396. Maxilla, internal antorbital fenestra, point of rostralmost incursion, relative to the teeth, lateral view: between the middle and caudal third of the tooth row at six tooth positions ahead of its caudal end (0), positioned at five teeth from the caudal end of the tooth row (1), positioned within less than five teeth of the caudal end of the tooth row (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5027 (2).

397. Maxilla, number of teeth rostral to the external antorbital fenestra: seven (0), six (1), less than six (2). **ORDERED**

Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1), CM 9380 (2).

398. Maxilla, number of teeth rostral to the intermaxillary process: three (0), two or less (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: This is in reference to the notch that separates the process from the bone.

399. Maxilla, number of tooth positions caudal to the medial interfenestral strut, medial view: six or seven (0), five or less (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

400. Maxilla, medial alveolar process, foramina, size, medial view: small (0), large (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

401. Maxilla, medial alveolar process, caudal end below palatine, texture, medial view: lightly coarse (0), rugose (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

402. Maxilla, interdental plates, orientation, ventral view: parallel with lateral alveolar process (0), rostral and caudal halves extend medially (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

403. Maxilla, interdental plates, round gaps between bases, through which tips of replacement teeth can be seen, medial view: gaps absent (0), gaps present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

404. Maxilla, interdental septa, orientation, ventral view: most are normal to the lateral alveolar process or slightly oblique (0), septa extend from rostrolaterally to caudomedially up to the extreme that they imbricate (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

405. Maxilla, tooth row, position of the last alveolus relative to the caudalmost foramen of the alveolar row of foramina, lateral and ventral views: below or caudal to foramen (0), rostral to foramen (1).

Exemplars: RSM 2347.1 (0), AMNH FARB 5027 (1).

406. Maxilla, palatal process, caudalmost extent of trough medial to tooth root bulges in the maxillary antrum, dorsal view: caudal end of the palatal process (0), base of the lateral interfenestral strut or below rostral end of the internal antorbital fenestra (1), limited to the antrum (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1), CM 9380 (2).

407. Maxilla, palatal process, tooth root bulges caudal to the maxillary antrum, size, medial view: distinct or partly obscured (0), partly obscured (1), completely obscured (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), CM 9380 (2).

408. Maxilla, palatal process, groove lateral to medial interfenestral strut and medial to tooth bulges, caudal end, depth, dorsal view: fades over the dorsal surface (0), deeply inset caudal end (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

409. Maxilla, palatal process, groove medial to the tooth root bulges within the maxillary antrum, depth, dorsal view: shallow (0), deep and not differentiated into three recesses (1), deep and differentiated into three or more recesses (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

410. Maxilla, joint surface for the palatine, mediolateral depth and form, medial view (Carr, 1999): ridged caudally, deep groove rostrally (0); flat caudally, groove rostrally (1); peg-in-socket caudally, groove rostrally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1), MOR 980 (2).

Ontogeny: This character was first described in Carr (1999) for *A. libratus* and *D. torosus*.

411. Maxilla, palatal process, caudal extent, dorsoventral position, medial view: extends medioventrally below the level of the medial alveolar margin (0), extends above the level of the margin (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

412. Maxilla, palatal process, joint surface for the palatine, dorsal view: rostral half is visible as a deep and coarse groove (0), faces medially and is out of view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

413. Maxilla, palatal process, joint surface for the palatine, ridge and notch at midlength, presence, medial and ventral views: absent (0); ridge is short and coarse and the notch is shallow (1); ridge is long, wide and coarse, notch is deep (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

414. Maxilla, palatal process, distance from the dorsal jugal process, medial and dorsal views: widely separated (0), close together to produce a narrow slot (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

415. Maxilla, palatal process, extent of the bony choana, medial view: caudal, extends to level of alveolus 11 (0); intermediate, alveoli 6-9 (1); rostral, alveoli 5-7 (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: This character refers to the rostrocaudal extent of the smooth nonjoint surface of the palatal process between the intermaxillary joint surface rostrally and the joint surface for the palatine caudally. In order to include data from isolated or disarticulated maxillae, it does not refer to the entire boundary of the bony choana as formed by the maxilla and palatal bones.

416. Maxilla, palatal process, contours, dorsal and ventral views: abruptly widens medially as the palatine rapidly thins rostrally (0), abrupt widening is not seen since the medial edge of the shelf continuously widens rostrally (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

417. Maxilla, medial alveolar process, interdental pits, caudal extent, medial view: alveolus 12 or greater (0), alveolus 11 or less (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

418. Maxilla, medial alveolar process, rostral interdental pits, depth, medial view: shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

419. Maxilla, joint surface for the jugal, rostral extent, medial view: stops caudal to last alveolus or extends over the last alveolus (0), reaches the second last alveolus (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

420. Maxilla, joint surface for the jugal, form, dorsal view: narrow and deep slot (0), smooth and shallow facet (1), coarse texture (2). **ORDERED**

Exemplars: RSM 2347.1 (0), BMRP 2002.4.1 (1), MOR 1125 (2).

421. Maxilla, dorsal jugal process, joint surface for the jugal, position, lateral view: does not reach the dorsal margin of the process (0), reaches the dorsal margin (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

422. Maxilla, jugal ramus, angle of divergence from the alveolar region, lateral view: straight or low angle (0), distinct angle (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

423. Maxilla, jugal ramus, jugal processes, separation between processes, lateral view: separated by a deep notch (0), connected by a caudoventrally-extending web of bone (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

424. Maxilla, jugal ramus, mediolateral width caudal to tooth row, ventral view: wide and flat (0); narrow, where the palatal process reduces in width (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

425. Maxilla, ventral jugal process, dorsoventral height, lateral view (Carr and Williamson, 2004: 25): shallow (0), deep (1).

Exemplars: RSM 2347.1 (0), CM 9380 (1).

Ontogeny: Variant of ontogenetic character 25 from Carr and Williamson (2004).

426. Maxilla, ventral jugal process, distal end, level relative to the lacrimal, lateral view: caudal to lacrimal (0), below lacrimal (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

427. Maxilla, ventral jugal process, form, lateral view: flat (0); subtly convex in vertical section and strut-like (1); massive, dorsoventrally deep and convex strut that extends caudoventrally to the tip of the bone (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

LACRIMAL (113 characters)

428. Lacrimal, antorbital fenestra, closure, rostralateral and medial views: marginal bone absent (0), marginal bone present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: Marginal bone refers to small or large spicules of bone that extend rostrally beyond the rostralateral boundary of the bone, forming an irregular fringe from, usually, the coarse subcutaneous surface.

429. Lacrimal, subcutaneous surface, degree of texture, dorsal and lateral views: lightly textured (0), coarse (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

430. Lacrimal, coarse patch caudodorsal to lacrimal pneumatic recess, presence, lateral view: region is a dorsoventrally low, coarse ridge (0); a ridge or a patch is absent (1); a discrete, coarse patch is present (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), RSM 2990.1 (1), CM 9380 (2).

431. Lacrimal, dorsal ramus, dorsolateral surface (from supraorbital ramus to tip of rostral ramus), texture, lateral view: rough, coarsened by numerous small papillae, surface

around lacrimal pneumatic recess is smooth (0); coarse, massive papillae coarsen the dorsolateral surface, especially the lateral surface of the supraorbital ramus and rostral ramus (1); rugose, where the papillate patch on the supraorbital ramus is dissected by deep neurovascular grooves, and spicule-like papillae occur dorsal to the lacrimal pneumatic recess and at the rostroventral edge of the rostral ramus (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

432. Lacrimal, dorsal ramus, widest region, dorsal view: caudal end of ventral ramus (0), across apex of the cornual process above rostral end of ventral ramus (1), midlength or caudal end of ventral ramus (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

433. Lacrimal, dorsal ramus, medial margin, dorsal view: not extended medially, gently convex, but nearly straight (0); extended medially and convex (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

434. Lacrimal, dorsal ramus, medial fossa, rostral ridge, medial view: present (0), absent (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: The terms *medial fossa* and *conchal surface* are used interchangeably throughout this section.

435. Lacrimal, dorsal ramus, medial fossa, dorsal ridge, presence and size, medial view: bounded dorsally by a prominent ridge (0); bounded caudodorsally, dorsally, and rostradorsally by a prominent ridge (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

436. Lacrimal, dorsal ramus, medial fossa, dorsal ridge, dorsoventral height of the caudal part of the ridge, medial view: shallow (0); dorsoventrally inflated, limiting the fossa rostral to the level of the joint surface for the prefrontal (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

437. Lacrimal, dorsal ramus, medial fossa, mediolateral depth, medial view: deep (0), shallow (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

438. Lacrimal, dorsal ramus, medial fossa, dorsal region of fossa, foramen, dorsoventral position, medial view: present at midheight of fossa (0), close to dorsal margin of fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

439. Lacrimal, dorsal ramus, conchal surface, form above medial pneumatic recess, rostral view: narrow and concave (0), convex (1).

Exemplars: FMNH PR2411 (0), RSM 2523.8 (1).

Note: The terms *conchal surface* and *medial fossa* are used interchangeably throughout this section.

440. Lacrimal, dorsal ramus, prefrontonasal joint surface above the medial fossa, medial view: deeply incised and dorsoventrally shallow slot (0); dorsoventrally deep, shallow groove that twists to face mediodorsally toward the supraorbital ramus (1); flat, coarse, and medially-facing facet that caudally twists to face dorsally or mediodorsally (2). **ORDERED**
Exemplars: RSM 2347.1 (0), MOR 1125 (1), CM 9380 (2).

441. Lacrimal, dorsal ramus, joint surfaces for the prefrontal and nasal, boundary between joint surfaces, distinctness, medial view: indistinct, surfaces are continuous (0), surfaces clearly separated by a groove (1); clearly separated by a ridge (2). **ORDERED**
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

442. Lacrimal, dorsal ramus, joint surface for the nasal, distal extent, position, dorsal view: limited to the medial surface of the ramus (0), extends onto the dorsal surface of the ramus (1).
Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

443. Lacrimal, dorsal ramus, dorsal surface medial to the cornual process, lateral-to-medial slope, caudal and dorsal views: not inflated and extends ventromedially at a low angle (0), slopes ventromedially at a steep angle (1), inflated and extends at a low angle ventromedially (2), dorsomedially (3). **ORDERED**
Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), RSM 2990.1 (2), CM 9380 (3).

444. Lacrimal, dorsal ramus, joint surface for the prefrontal, separation from the conchal surface, medial view: prominent ridge separates the surfaces (0), ridge is low caudal to conchal surface (1).
Exemplars: FMNH PR2411 (0), CM 9380 (1).

445. Lacrimal, dorsal ramus, joint surface for the prefrontal, exposure, dorsal view: not exposed to dorsal view (0), exposed (1).
Exemplars: FMNH PR2411 (0), CM 9380 (1).

446. Lacrimal, dorsal ramus, joint surface for the ventral arm of the prefrontal, form, medial view: flat and lightly rugose (0), peg-in-socket (1).
Exemplars: FMNH PR2411 (0), CM 9380 (1).

447. Lacrimal, dorsal ramus, region dorsal and rostradorsal to the lacrimal pneumatic recess, lateral view (Carr, 1999): concave (0), convex adjacent to recess, dorsolateral surface is flat or entire surface is convex (1).
Exemplars: FMNH PR2411 (0), CM 9380 (1).
Ontogeny: First described in Carr (1999); transition from dished to not dished.

448. Lacrimal, dorsal ramus, region caudal to the lacrimal pneumatic recess, form, lateral view (Carr, 1999): concave (0), inflated and convex (1).
Exemplars: FMNH PR2411 (0), CM 9380 (1).
Ontogeny: Variant of character first described in Carr (1999); transition from dished to not dished.

449. Lacrimal, dorsal ramus, subcutaneous surface, height relative to the joint surface for the nasal, rostral view: marginally taller or shorter (0), significantly taller than the joint surface (1).

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1).

450. Lacrimal, conchal surface, caudodorsal surface, form, medial view: concave (0), convex (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

451. Lacrimal, conchal surface, caudal margin, rostrocaudal position, medial view: positioned far rostrally, away from the frontal process (0); extends caudally onto the base of the frontal process (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

452. Lacrimal, frontal process, foramen in rostral surface, medial view: absent (0), present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

453. Lacrimal, cornual process, lateral view (Carr, 1999): distinct (0), reduced by inflation (1), obliterated by pneumatic inflation (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

Ontogeny: Variant of character first described in Carr (1999); transition from weak ridge to pronounced apex in *A. libratus* and extreme inflation in *D. torosus* and *T. rex*.

454. Lacrimal, cornual process, lateral extent, rostral view: level with the ventral ramus (0), extends laterally beyond the ventral ramus (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

455. Lacrimal, lacrimal pneumatic recess, foramen in ventral margin, lateral view: present (0), absent (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

456. Lacrimal, lacrimal pneumatic recess, ridge within recess, width and size, lateral view: narrow and small, where it does not reach the rostral septum (0); wide and large, where it reaches the septum (1).

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1).

457. Lacrimal, rostral ramus, region below the lacrimal pneumatic recess, lateral view: not inflated (0), inflated such that it extends rostradorsally by merging with the septum rostral to the recess (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

458. Lacrimal, rostral ramus, septum rostral to lacrimal pneumatic recess, rostrocaudal length, lateral view: rostrocaudally short (0), long (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: This is almost certainly equivalent to the presence or absence of the proximal accessory recess, and it is included here to test that hypothesis.

Result: Character 458 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

459. Lacrimal, rostral ramus, septum that bounds the lacrimal recess rostrally, inflation, lateral view: not inflated (0), intermediate (1), fully inflated (2). **ORDERED**

Exemplars: FMNH PR2411 (0) RSM 2990.1 (1), CM 9380 (2).

460. Lacrimal, rostral ramus, septum rostral to lacrimal recess, presence of a foramen in its lateral surface, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

461. Lacrimal, region caudal and caudodorsal to the lacrimal pneumatic recess, lateral view: short and shallow (0); intermediate (1); long, deep, and inflated (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

462. Lacrimal, lacrimal pneumatic recess, length of recess relative to the bone caudal to it below the level of the supraorbital ramus, lateral view: recess is greater than half the length (0), recess is less than half the length (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

463. Lacrimal, rostral ramus, caudal extent of the joint surface for the nasal, dorsal view: stops rostral to the ventral ramus (0), extends medial to the ventral ramus (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

464. Lacrimal, rostral ramus, rostradorsal margin, lateral view: convex (0), slopes gently rostroventrally above the distal recess (1), slopes abruptly rostroventrally above the distal recess (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), RSM 2990.1 (1), CM 9380 (2).

Note: State 2 is almost certainly an epiphenomenon of expansion of nasals onto the dorsal surface and it is included here as a separate character to test that hypothesis.

Result: Character 464 was optimized unambiguously on the ontogram, but the corresponding nasal character was not; the hypothesis is unresolved.

465. Lacrimal, rostral ramus, depth of subcutaneous region, relative to the antorbital fossa, lateral view (Carr, 1999): less than half as deep as the depth of the fossa below it (0), twice as deep as the fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); progression from absent to low to as deep as the antorbital fossa.

466. Lacrimal, rostral ramus, junction of antorbital fossa and subcutaneous surface rostral to the pneumatic recess at the septum, lateral view (Carr, 1999): undercut (0), merged (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); transition from unfused to fused.

467. Lacrimal, rostral (=distal) recess, exposure, lateral view: widely exposed laterally (0), equally oriented ventrally and laterally (1); directed ventrally and minimally exposed laterally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), RSM 2990.1 (1), CM 9380 (2).

468. Lacrimal, proximal pneumatic recess (between lacrimal recess and distal pneumatic recess), presence and form, lateral view: deep recess (0), shallow fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: The presence of both a foramen and a recess in MOR 980 indicates that these structures are not homologous and they can be treated separately.

469. Lacrimal, rostral ramus, antorbital fossa, rostrocaudal length of septum between the accessory recesses, lateral view: short (0); long, where the proximal recess is reduced to a fossa or is absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

470. Lacrimal, accessory pneumatic recesses, proximity to the maxilla contact, lateral view: does not closely approach (0), approaches or reaches (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

471. Lacrimal, distal accessory recess, form, lateral view: deep fossa (0), shallow fossa (1), discrete pneumatic foramen (2), small neurovascular foramen (3). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), RSM 2990.1 (1), CM 9380 (2), MOR 980 (3).

472. Lacrimal, ventral edge of subcutaneous ala ahead of the septum that bounds the lacrimal pneumatic recess rostrally, form, lateral view: extends distinctly rostrorodorsally along a dorsally concave arc (0), extends rostroventrally or grades into the antorbital fossa without a distinct orientation (1).

Exemplars: FMNH PR2411 (0), RSM 2523.8 (1).

473. Lacrimal, rostral ramus, joint surface for caudolateral process of nasal, coverage of rostrorodorsal process, lateral view: covers ventral edge of distal end of rostrorodorsal process (0), shallow concavity on ventral third or more of process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

474. Lacrimal, rostral ramus, medial joint surfaces, depth of dorsal and ventral regions, medial view: dorsal almost as deep as ventral (0), dorsal shallower than ventral (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

475. Lacrimal, rostral ramus, joint surface caudal to medial tube, form, medial view: convex (0), concave (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

476. Lacrimal, rostral ramus, groove that extends rostrally from medial tube, dorsal margin, medial view: level with the dorsal margin of the tube (0); extends rostradorsally from the tube, deepening the groove rostrally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

477. Lacrimal, rostradorsal process depth, lateral view: shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: In the *shallow* condition the process abruptly tapers rostrally relative to the ramus behind it; in the *deep* condition the process is wedge-shaped and does not taper abruptly as it extends rostrally.

478. Lacrimal, rostral ramus, rostradorsal process, position relative to the internal antorbital fenestra, lateral view: short, extends to the midlength of the internal antorbital fenestra (0); long, extends rostrally past the midlength of the fenestra (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

479. Lacrimal, rostral ramus, rostroventral process, position, lateral view: does not separate the maxilla from the nasal (0), separates the maxilla from the nasal (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

480. Lacrimal, rostral ramus, rostroventral process, length relative to the rostradorsal process, lateral view (Carr, 1999): absent (0), longer than the rostradorsal process (1), same length or shorter than the rostradorsal process (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), RSM 2990.1 (1), CM 9380 (2).

Ontogeny: First described in Carr (1999) as a progression from absent, to short, and then to long.

481. Lacrimal, rostral ramus, maxillary process, depth, lateral view: dorsoventrally deep (0), intermediate to a thin sliver (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

482. Lacrimal, supraorbital ramus, caudolateral shelf, form, lateral view (Carr, 1999): present but indistinct (0); present, distinct (1); eliminated by inflation (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: In part equivalent to the “swollen above orbits” condition observed by Bakker et al. (1988:5).

Ontogeny: Variant of character first described in Carr (1999); transition from absent to present in *A. libratus* and elimination by inflation in *D. torosus* and *T. rex*.

483. Lacrimal, supraorbital ramus, direction, dorsal view: curves caudomedially (0), caudolateral edge extends laterally beyond the edge of the bone (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: The structure that extends laterally is a stout process that abutted the rostral end of the lacrimal osteoderm, which caps the caudodorsolateral surface of the bone.

484. Lacrimal, supraorbital process, width to height ratio, caudal view: as wide as tall (0), deeper than wide or wider than tall (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: In part equivalent to the “swollen above orbits” observation made by Bakker et al. (1988:5).

485. Lacrimal, supraorbital process, dorsal surface, width, dorsal view: narrow, longer than wide (0); as wide as long (1); wide, wider than long (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: In part equivalent to the “swollen above orbits” observation made by Bakker et al. (1988:5).

486. Lacrimal, supraorbital process, orientation of the joint surface for the frontal, dorsal view: rostrocaudal (0), rostralateral (1), rostromedial (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

487. Lacrimal, supraorbital ramus, medially extending process behind joint surface for the prefrontal, presence, caudal, medial, and dorsal views: indistinct (0); distinct (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

488. Lacrimal, angle between supraorbital ramus and the ventral ramus, lateral view: distinct (0), continuous and indistinct (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

489. Lacrimal, joint surface for the frontal, dorsal surface of peg is excavated by a deep mediolaterally-extending groove, dorsal view: absent (0), present (1).

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1).

490. Lacrimal, ventral ramus, joint surface for the ventral arm of the prefrontal, exposure, caudal view: only the distal end is exposed to view (0); entirely in view (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

491. Lacrimal, caudal joint surface, lateral extension, dorsoventral position, caudal view: no joint surface on caudal end of supraorbital process (0), at midheight of ramus (1); below midheight (2). **ORDERED**

Exemplars: FMNH PR2411(0), MOR 1125 (1), FMNH PR2081 (2).

492. Lacrimal, rostroventral ala, rostral margin, form, lateral view (Carr, 1999): concave (0), straight (1), convex (2). **ORDERED**

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Ontogeny: First described in Carr (1999) as a transition from straight to convex.

493. Lacrimal, medial pneumatic recess, absorption of the caudoventral margin, medial view: absorption of caudoventral edge is absent (0), absorption is present (1).

Exemplars: RSM 2990.1 (0), CM 9380 (1).

Note: Specimens lacking the recess are coded as inapplicable (“?”) since their absence is already coded above.

494. Lacrimal, medial pneumatic recess, distance from rostral margin of ventral ramus, medial view: closely approaches (0), far caudal to margin (1).

Exemplars: RSM 2990.1 (0), CM 9380 (1).

Note: Specimens lacking the recess are coded as inapplicable (“?”) since their absence is already coded above.

495. Lacrimal, medial pneumatic recess, depth into bone, rostromedial view: a deep fossa of limited caudodorsolateral extent (0); invasive, where it extends deeply caudodorsolaterally into the dorsal ramus (1).

Exemplars: MOR 2822 (0), CM 9380 (1).

Note: Specimens lacking the recess are coded as inapplicable (“?”) since their absence is already coded above.

496. Lacrimal, medial pneumatic recess, horizontal septum at midheight, presence, medial view: present (0), absent (1).

Exemplars: MOR 2822 (0), CM 9380 (1).

Note: Specimens lacking the recess are coded as inapplicable (“?”) since their absence is already coded above.

497. Lacrimal, vascular sulcus above medial pneumatic recess, or in homologous region in specimens where the medial pneumatic recess is absent, medial view: shallow (0), deep (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

498. Lacrimal, ventral ramus, width below the dorsal ramus, rostral view: narrow (0), wide (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

499. Lacrimal, ventral ramus, surface ahead of orbitonasal ridge and below medial pneumatic recess, form, medial view: concave in vertical and horizontal sections (0), convex in vertical section (1).

Exemplars: BMRP 2002.4.1 (0), MOR 2822 (1).

500. Lacrimal, ventral ramus, caudal margin, proximal half, prominent ridge delimited ventrally by a notch, presence, lateral and medial views: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

501. Lacrimal, ventral ramus, junction with the antorbital fossa of the dorsal ramus, lateral and rostral views (Carr, 1999): merge (0), separated by a narrow groove (1).

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1).

Ontogeny: First described in Carr (1999); transition from merge to edge.

502. Lacrimal, orbitonasal ridge, rostrocaudal length proximally and distally, medial view: wide proximally, wide distally (i.e., same length) (0); wide proximally, narrow distally (i.e., different lengths) (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

503. Lacrimal, orbitonasal ridge, medial edge, form, medial view: medial edge is distally backswept (0), not backswept (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

504. Lacrimal, orbitonasal ridge, mediolateral width, rostral view: narrow (0); wide, but tapers ventrally (1); wide (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

505. Lacrimal, orbitonasal ridge, mediolateral width, caudal view: entire ridge is narrow (0), extends medially at the midheight of the ventral ramus (1), entire ridge is widened medially (2).

ORDERED

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: This character is included to assess whether or not it is equivalent to the width as seen in rostral view.

506. Lacrimal, orbitonasal ridge, largest foramen at the upper corner of the orbit, shape, caudal view: dorsoventrally deep and narrow (0), rounded (1).

Exemplars: FMNH PR2411 (0), CM 9380.

507. Lacrimal, orbitonasal ridge, largest foramen at the upper corner of the orbit, pit, presence, caudal view: foramen is not in a pit (0), foramen is situated in a deep pit (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

508. Lacrimal, orbitonasal ridge, caudomedial edge, form, caudal view: mediolaterally narrow (0), wide mediolaterally and rostrocaudally thin ridge (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

509. Lacrimal, orbitonasal ridge, contact between the rostral margin of the ridge and the ventral ramus, medial view: surfaces are separated by a crease (0), surfaces grade into each other (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

510. Lacrimal, orbitonasal ridge, position of curled caudal edge, medial view: closely approaches the caudal margin of the ventral ramus above where the ventral ramus and ala cross (0), edge is far rostral to the caudal edge (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

511. Lacrimal, orbitonasal ridge, point where it extends rostroventrally, medial view: at the rostroventral ala (0), at or above midheight of ventral ramus (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

512. Lacrimal, ventral ramus, distance between the leading edge of the ventral ramus from the rostroventral ala, lateral and rostral views: not widely separated (0), widely separated from each other (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

513. Lacrimal, ventral ramus, leading edge, junction with rostroventral ala above jugal contact, lateral view: separated by a groove or crease (0), surfaces merge together (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

514. Lacrimal, ventral ramus, suborbital ligament scar, interruption of the orbit margin, lateral view: subtle (0), distinct (1).

Exemplars: FMNH PR2411 (0), BMRP 2002.4.1 (1).

515. Lacrimal, suborbital ligament scar, degree of texture, lateral view: lightly coarse (0), coarser than the subcutaneous surface (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

516. Lacrimal, suborbital ligament scar, form, lateral view: flat (0), convex or bulbous (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

517. Lacrimal, ventral ramus, subcutaneous surface, width of dorsal region compared with ventral half, lateral view (Carr, 1999): dorsal end narrower than ventral end (0), dorsal end wider than ventral end (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: In CMNH 7541, the proximal and distal ends on both sides appear to be approximately the same length, but in dorsal view it is seen that the distal end is telescoped, artificially reducing the rostrocaudal length of the distal (=ventral) end of the ramus.

Ontogeny: Variant of adult character state that was first described in Carr (1999) for *D. torosus*.

518. Lacrimal, ventral ramus, rostroventral extent, rostral extension along jugal, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

519. Lacrimal, ventral ramus, width of ventral end next to junction with rostroventral ala, rostral view: narrow (0), wide (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

520. Lacrimal, ventral ramus, fossa between the prefrontal joint surface and ventral ramus, caudal view: shallow (0), deep and sharply delimited laterally by a distinct ridge (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

521. Lacrimal, ventral ramus, rostradorsal margin, inflation, rostral view: not inflated, narrow, medial surface is flat (0); inflated, wide, and columnar proximally (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

522. Lacrimal, ventral ramus, rostradorsal margin, form, lateral view: convex (0), straight or concave (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

523. Lacrimal, ventral ramus, subcutaneous surface, texture, lateral view: wrinkled (0); coarse, small papillae concentrated toward the rostral margin of the ramus (1); rugose, entire lateral surface is coarsened by papillae, ridges, and especially large, rostroventrally extending neurovascular grooves (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

524. Lacrimal, ventral ramus, caudal (subcutaneous) surface, extension onto the caudal surface proximally, caudal view: does not extend onto caudal surface, except marginally (0); extends widely onto caudal surface, laterally bounds caudal fossa (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

525. Lacrimal, ventral ramus, medial surface of caudal half of ventral ramus, including rostroventral ala, medial view: smooth (0), scoured by deep and torturous vascular sulci (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

526. Lacrimal, ventral ramus, rostroventral margin, form, lateral view: convex, confluent with rest of shaft (0); straight (1); concave (2). **ORDERED**

Exemplars: FMNH PR2411 (0), RSM 2990.1 (1), CM 9380 (2).

527. Lacrimal, ventral ramus, ventral margin, direction of rostral half (from notch in ventral margin) to rostral tip of margin, medial view: rostradorsal (0), horizontal or rostroventral (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

528. Lacrimal, ventral ramus, subcutaneous surface, caudoventrally extending sulcus, presence, lateral view: absent (0), present (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

Note: This torturous sulcus extends caudoventrally across the lateral surface of the ramus from below the lacrimal pneumatic recess to the midheight of the caudal margin of the ventral ramus.

529. Lacrimal, rostroventral ala, joint surface for the palatine, extent, medial view: covers the rostral third of the distal end of the bone (0), covers only a quarter or less of the distal end (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

530. Lacrimal, rostroventral ala, contact with the palatine, surface of contact, position, medial, rostral, and lateral views: present medially only (0); present medially and rostrally (1); medial, rostral, and laterally (2). **ORDERED**

Exemplars: FMNH PR2411 (0), AMNH FARB 5017 (1), CM 9380 (2).

531. Lacrimal, rostroventral ala, joint surface for the palatine, depth, medial view: vanishingly shallow (0), deeply inset (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

532. Lacrimal, rostroventral ala, rostral surface, dorsoventral extent of the joint surface for the palatine: extends halfway up the ala (0), extends up the ventral two-thirds of the ala or more (1).

Exemplars: FMNH PR2411 (0), CM 9380 (1).

533. Lacrimal, ventral ramus, jugal suture, degree of slope, lateral view: less than 45 degrees (0), 45 degrees or steeper (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: this angle can also be deduced from the joint surface for the lacrimal on the jugal.

534. Lacrimal, ventral ramus, caudoventral margin of the jugal contact, orientation, lateral view (Carr, 1999): 45 degrees or less (0), greater than 45 degrees or caudoventral (1).

Exemplars: CMNH 7541 (0), CM 9380 (1).

Ontogeny: First described in Carr (1999); transition from subvertical to caudodorsal.

JUGAL (70 characters)

535. Jugal, maxillary ramus, height relative to the orbit, lateral view (Carr, 1999): lower than floor of orbit (0), dorsal to floor (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from shallow to deep.

536. Jugal, maxillary ramus, antorbital fossa, contact with the ventral margin of the maxillary ramus, lateral view: reaches ventral margin (0), does not reach ventral margin (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Note: In the mature condition, the subcutaneous surface prevents the fossa from reaching the ventral margin of the ramus.

537. Jugal, maxillary ramus, joint surface for the dorsal jugal process of the maxilla, extent relative to the pneumatic recess, lateral view: above the rostral end of recess (0), rostral to the recess (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

538. Jugal, maxillary ramus, joint surface for the maxilla (wide medial part, not the narrow lateral slit), medial view: flat facet (0), shallow groove (1), ends in a deep groove (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

539. Jugal, maxillary ramus, joint surface for the maxilla, proximity to the ventral margin of the bone, medial view: caudal end of the dorsal margin does not reach the ventral margin (0), reaches the ventral margin (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

540. Jugal, maxillary ramus, medial joint surfaces for the maxilla and the lacrimal, dorsoventral separation, medial view: narrow separation (0), widely separated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

541. Jugal, maxillary ramus, medial joint surface for the lacrimal, caudal extent, orientation, medial view: extends at a low rostroventral angle (0), steep angle or vertical (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

542. Jugal, maxillary ramus, medial joint surface for the lacrimal, proximity to the caudal margin of the maxillary ramus, medial view: closely approaches caudal margin of ramus (0), widely separated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: This can also be expressed as the distance between the joint surface and the orbit margin, where there is no separation or only a narrow sliver of bone between them (0), or a wide and flat wedge separates the structures (1).

543. Jugal, maxillary ramus, margin of joint surface for lacrimal at midheight, depth, medial view: deeply inset caudal margin (0); only inset caudodorsally, rest of the region is smooth (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

544. Jugal, lateral maxillary process, slit, presence, lateral view: the process is a single-unit structure (0), the process is separated into subordinate dorsal and ventral processes by a slit that extends caudally from its rostral tip (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

545. Jugal, medial maxillary process, midregion of joint surface for the maxilla, orientation, medial view: faces more medially than ventrally (0), faces medioventrally or more ventrally than medially (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

546. Jugal, medial maxillary process, rostral end above joint surface for the maxilla, medial view: extends rostrolaterally, but is not inset caudally (0); not sharply inset caudally (1); sharply inset caudally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 555 (2).

547. Jugal, jugal pneumatic recess, rostral margin, form, lateral view: rostrocaudally short and convex rostral margin (0), rostrocaudally long and angular rostral margin (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

548. Jugal, jugal pneumatic recess, dorsoventral height, lateral view: tall, spans the height of the antorbital fossa (occupies more than half the height of the fossa) (0); short and limited dorsally, where it does not extend to the ventral margin of the fossa and so occupies approximately half the height of the antorbital fossa (1).

Exemplars: MOR 1125 (0), MOR 980 (1).

Note 1: In the *tall* condition, the rostroventral margin is absorbed, forming a convex rostral margin of the recess and an overall tall shape. In the *limited* condition, the rostroventral margin of the opening is not absorbed, forming a pointed rostral margin of the recess; ergo, in subadults

the rostroventral part of the opening has a truncated appearance, which makes the opening look unusually short.

Note 2: This character is coded as inapplicable in juveniles where the maxillary ramus and the jugal pneumatic recess are not dorsoventrally expanded.

549. Jugal, jugal pneumatic recess, caudal end of recess and caudal margin of recess, position, lateral view: caudal ends of both end at same point (0), margin of recess extends caudal to where it rejoins the bone (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

550. Jugal, jugal pneumatic recess, rostroventral margin, lateral view: not absorbed, forming a pointed rostral margin of the recess (0); absorbed, forming a convex rostral margin of the recess (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

551. Jugal, secondary fossa, medial wall, strut, presence, lateral view: absent (0), present (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

552. Jugal, secondary fossa, dorsal margin, depth of inset, lateral view: deeply inset rostrally, not inset caudally (0), entire margin is deeply inset (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

553. Jugal, antorbital fossa, position relative to caudal margin of the jugal pneumatic recess, lateral view: fossa does not separate the recess from the subcutaneous surface (0), fossa separates most of the recess from the subcutaneous surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

Note: Stated another way, the recess extends along the subcutaneous surface in the immature condition, whereas in the mature condition the antorbital fossa extends caudally past the caudal margin of the recess to excavate the subcutaneous surface behind the recess.

554. Jugal, antorbital fossa, direction of its lateral margin as it extends dorsally away from the recess, lateral view: extends caudodorsally toward the joint surface for lacrimal (0), extends rostradorsally from the recess (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

555. Jugal, antorbital fossa, accessory pneumatic recess rostral or caudal to the primary jugal pneumatic recess, presence, lateral view: absent (0), present (1).

Exemplars: CMNH 7541, MOR 555 (1).

556. Jugal, body, texture in region of greatest width, degree, lateral view: lightly coarse (0); rugose, deeply dissected, papillate (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

557. Jugal, body of the bone, depth, lateral view: deep, where the dorsal margin in the region of orbital fenestra is shallowly concave (0); shallow, dorsal margin in region of orbital fenestra is deeply concave (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

558. Jugal, body of the bone, lateral extent of the inflated region, lateral and ventral views: widest region does not extend lateral (or extends marginally lateral) to the cornual process (0), extends lateral to the cornual process (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Note: This character captures the relative degree of inflation of the body of the bone, relative to a fixed point of reference, the cornual process.

559. Jugal, body of the bone, lateral margin, dorsal view: convex from below the joint surface for the lacrimal to the rostral half of the postorbital process (0), convex from the orbital fenestra to the base of the quadratojugal process (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

560. Jugal, body of the bone, medial surface, number of foramina, medial view: six or more (0), less than six (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

561. Jugal, orbital fenestra, dorsal margin, position, dorsal view: along the medial edge of the bone (0), midway between the lateral and medial edges or toward the lateral edge (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

562. Jugal, cornual process, relative size, lateral view (Carr, 1999): prominent, strongly delimited relative to ventral margin behind it (0); low, caudal edge is not strongly delimited, where ventral margin of bone slopes uninterrupted to the process (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

Ontogeny: Character first described in Carr (1999); transition from pronounced to low.

563. Jugal, cornual process, mediolateral width, ventral view (Carr, 1999): narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2535.8 (1).

Note: The rostral half of the process is excavated by the joint surface for the ectopterygoid, which reduces the process to a narrow flange, whereas the caudal half of the process bulges medially behind the joint surface. In the *narrow* condition, the lateral surface of the process is flat; in contrast, in the *wide* condition, the process extends laterally to widen the structure and simultaneously widens the narrow flange alongside the ectopterygoid.

Ontogeny: Character first described in Carr (1999); transition from narrow to wide.

564. Jugal, cornual process, ventral surface, divided by a medioventrally-extending groove, medial, lateral, and ventral views: present at rostral end of process (0), present caudal to rostral end (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

565. Jugal, cornual process, texture, lateral and ventral views: lightly rugose (0), rugose (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

566. Jugal, ventral margin rostral to the cornual process, orientation, ventral view: extends to the lateral edge of the cornual process (0), extends to the medial edge of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

567. Jugal, width of the region ahead of the cornual process, ventral view: narrow and bounded medially by a thin and deep ridge (0); wide, ridge is low and wide or it is nearly obliterated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

568. Jugal, joint surface for the ectopterygoid, rostral end, delimited by a notch, medial view: notch present (0), notch absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: In the *notched* condition, a square corner is formed in the smooth medial surface between the joint surface for the ectopterygoid and that for the maxilla; in the *notch absent* condition, the smooth medial surface extends caudoventrally as a triangular ridge that pinches out between the joint surfaces.

569. Jugal, postorbital process, lateral depression, rostrocaudal position, lateral view: caudal to the rostral extent of the postorbital contact (0), approaches (1), reaches the level of the rostral end of the postorbital contact (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

570. Jugal, postorbital process, strut rostral to lateral depression, lateral view: absent (0); transversely narrow and indistinct (1); prominent, strongly convex, and extends toward distal end of process (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 555 (2).

Note: This ridge is not homologous to character 100 from Carr et al. (2017).

571. Jugal, postorbital process, vertical distance between ventral end of joint surface for the postorbital and top of the quadratojugal process, ratio with depth below orbit, lateral view: low (50% or less) (0), deep (50% or greater) (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

572. Jugal, postorbital process, fossa between the postorbital and quadratojugal processes, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

573. Jugal, joint surface for the postorbital, form, rostral and lateral views: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

574. Jugal, joint surface for the postorbital, mediolateral width, rostral view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

575. Jugal, joint surface for the postorbital, orientation at midheight, rostral view: faces rostrally (0), faces laterally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

576. Jugal, joint surface for the postorbital, proximal portion (closest to orbit margin), exposure, lateral view: proximal portion of the joint surface for the postorbital is exposed (0), region is concealed by the subcutaneous surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

577. Jugal, region of lateral surface between the cornual process and quadratojugal ramus, lateral view: gently convex in vertical section (0), strongly convex (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

578. Jugal, dorsal quadratojugal process, proximal end of joint surface, exposure, medial view: concealed (0), exposed (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

579. Jugal, joint surface for quadratojugal, mediolateral position of the ventral half of joint surface, dorsal view: same plane as dorsal quadratojugal process (0), extends lateral to base of dorsal process (1), far medial to dorsal process (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

580. Jugal, quadratojugal ramus, orientation, lateral view: caudoventral (0), caudodorsal (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

581. Jugal, ventral quadratojugal process, tilt of process along long axis, ventral view: tilted such that its lateral surface is visible (0), tilted such that the medial surface is visible (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

582. Jugal, joint surface for the quadratojugal, ventral margin, contact with ventral margin of bone, position, lateral view: caudal to the split between the quadratojugal processes (0), below or rostral to split (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

583. Jugal, joint surface for the quadratojugal, proximity to cornual process: approaches process (0), reaches caudal margin of cornual process (1), far caudal to process (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), FMNH PR2081 (2).

584. Jugal, joint surface for the quadratojugal (on both subordinate processes), texture, lateral view: coarsened by fine ridges and grooves (0), coarsened by distinct ridges and deeply incised grooves (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

585. Jugal, ventral quadratojugal process, width, lateral and dorsal views: narrow and flat-sided or base is narrow and flat-sided (0), dorsal half wider than ventral half (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

586. Jugal, ventral quadratojugal process, longitudinal ridge of joint surface, lateral view: at distal end and strongly convex (0), ridge is flattened (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

587. Jugal, ventral quadratojugal process, dorsal half of the joint surface at the base of the process, lateral and dorsal views: slopes lateroventrally (0); region is flat or grooved, oriented dorsally, and wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

588. Jugal, ventral quadratojugal process, dorsal margin of the base of the process, lateral view: broadly convex (0); scalpel-shaped, where the dorsal margin deepens before decreasing in height caudally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

589. Jugal, ventral quadratojugal process, medial surface, medial view: concave distally, far caudal to base of the process (0); the concavity extends proximally, but not to base (1); concavity extends to the base (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

590. Jugal, ventral quadratojugal process, dorsolateral surface, proximal region of process, lateral view: coarsened by fine grooves and ridges (0), coarsened by large ridges (1), dominated by a single large ridge (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

591. Jugal, ventral quadratojugal process, ridge below concavity, width, medial view: surface is flat, groove is absent (0), the ventral ridge does not extend ventromedially like a shelf (1), extends ventromedially like a shelf (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

592. Jugal, ventral quadratojugal process, joint surface at proximal end of process, exposure, medial view: not visible in medial view (0), visible in medial view (1), marginally in view (2).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1), RSM 2523.8 (2).

593. Jugal, ventral quadratojugal process, joint surface on dorsal surface of distal end, lateral view: extends and fades onto the lateral surface of the process (0), extends rostrally as deep groove almost to the base of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

594. Jugal, ventral quadratojugal process, proximal region of joint surface, form and orientation, ventral view: concave and not visible in ventral view (0), convex and exposed in ventral view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

595. Jugal, ventral quadratojugal process, midregion of joint surface, distal ridge, proximal extent, lateral view: fades rostrally as a low ridge (0), fades rostrally as a laterally wide and dorsoventrally shallow ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: The *low* condition indicates that the ridge does not extend laterally, the *wide* condition indicates that it does extend laterally.

596. Jugal, distance between ventral jugal process of the maxilla and the cornual process, lateral view: adjacent to each other (0), widely separated from each other (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

597. Jugal, medioventral ridge, presence, medial view: ridge is absent (0), indistinct ridge extends from cornual process to ventral quadratojugal process (1), massive ridge extends along the ventral margin of the bone from the cornual process to the tip of the ventral quadratojugal process (1).

Exemplars: CMNH 7541 (0), UWBM 99000 (1), FMNH PR2081 (2).

598. Jugal, medial joint surface for the quadratojugal, tab, presence, medial view: a small, caudally-extending tab does not overlap the rostral tip of the quadratojugal between the dorsal and ventral quadratojugal processes (0); a distinct, caudoventrally extending tab covers the rostral tip of the quadratojugal between the dorsal and ventral quadratojugal processes (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

POSTORBITAL (63 characters)

599. Postorbital, frontal process rugosity, presence, lateral view: absent (0), present (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

600. Postorbital, frontal process rugosity, rostral end, pedicle, presence, lateral view: absent (0), present but low (1), present and distinct (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 2822 (2).

601. Postorbital, frontal process, rugosity, dorsal margin, dorsolateral view: groove is absent (0), groove is present and extends longitudinally between the rugosity and the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

602. Postorbital, frontal process, dorsotemporal fossa, crease between postorbital buttress and shelf, presence, dorsal view: present (0), very shallow or absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

603. Postorbital, frontal process, dorsotemporal fossa, rostral ridge, presence, dorsal view (Carr, 1999): distinct (0), low (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Ontogeny: Character first described in Carr (1999); transition from absent to present.

604. Postorbital, joint surface for the frontal, texture, medial view: coarse (0), secured by deep slots and ridges (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

605. Postorbital, angle between frontal process and body of the bone, degree of angle, dorsal view: gradual curve (0), distinct angle (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

606. Postorbital, frontal process, ventrolateral surface, foramina, presence, ventrolateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

607. Postorbital, joint surface for the frontal, shelf that overlaps the frontal, medial view: extends horizontally (0), extends rostr dorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

608. Postorbital, joint surface for the frontal, shelf that overlaps the frontal, nature of the contact, medial view: strictly overlapping (0), a slot or slots (1), socket (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

609. Postorbital, joint surface for the frontal, length and depth, medial view: long and shallow (0), short and deep (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

610. Postorbital, joint surface for the postorbital buttress, orientation, dorsal view: faces almost directly medially (0), faces rostromedially to rostrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

611. Postorbital, joint surface for the postorbital buttress, medial half of the joint surface, rostral view: extends dorsally, vertically oriented (0); extends rostrally over the joint surface as a shelf (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

612. Postorbital, postorbital buttress, ventral half of the postorbital buttress, ventral margin, orientation, medial view: horizontal (0), extends steeply rostroventrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

613. Postorbital, cleft between processes for the frontal and laterosphenoid, dorsal and medial views: present, completely separates the processes dorsally and ventrally (0); closed dorsally (1); closed dorsally and ventrally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

614. Postorbital, laterosphenoid process, length relative to frontal process, dorsal view: extends further medially than the frontal process (0), frontal process extends further medially than the laterosphenoid process (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5117 (1).

615. Postorbital, joint surface for the laterosphenoid, form, medial view: flat, convex, or shallowly concave (0); deeply concave (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

616. Postorbital, laterosphenoid process, separation from frontal process, ventral view: a crease between the processes is present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

617. Postorbital, joint surface for the laterosphenoid, direction, medial view: dorsal part faces ventrally like a cupped palm (0), faces rostromedially like an ear (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

618. Postorbital, body, dorsal margin of the bone, orientation, dorsal view (Carr, 1999): vertical (0), everted medially (1), eversion obscured by mediolateral swelling of the bone (2).

ORDERED

Exemplars: CMNH 7541 (0), MOR 1125 (1), MOR 555 (2).

Ontogeny: Character first described in Carr (1999); transition from vertical to everted.

619. Postorbital, body, dorsal margin, width, dorsal view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

620. Postorbital, body of the bone, dorsal margin, form, medial view: subtly sinuous (0), subtly dorsally convex (1), tall and distinctly convex (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 1125 (2).

621. Postorbital, body of the bone, dorsomedial surface, rugosities, presence, medial view: rugosities do not extend onto medial surface (0), extend onto medial surface (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

622. Postorbital, body, surface between the contact for squamosal and frontal process (above medial fossa), form, medial view: gently concave, bounded dorsally by a ridge (0); flat or subtly convex (1); unambiguously convex (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150157 (1), MOR 555 (2).

623. Postorbital, body, dorsal margin along dorsotemporal fenestra, form, rostral view: low arch (0), distinctly convex and abruptly extends dorsally relative to the frontal process of the bone (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

624. Postorbital, body, medial fossa, depth, medial view: deep (0), shallow (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

625. Postorbital, body, medial fossa, dorsal margin, medial view: delimited by a prominent and sharp ridge (0), low and indistinct ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

626. Postorbital, cornual process, crease, presence, lateral view: undifferentiated (0), crease between ventral boss and dorsal ridge is present (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

627. Postorbital, cornual process, interruption of the rostrolateral corner of the dorsotemporal fossa, presence, dorsal view: does not interrupt (0), interrupts the corner (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

628. Postorbital, osteoderm, region of fusion, lateral, dorsal, caudal, and ventral views: fused dorsally only (0); fused dorsally, caudally and ventrally (1).

Exemplars: RSM 2523.8 (0), FMNH PR2081 (1).

629. Postorbital, osteoderm, ornamentation, presence, lateral view: two rows of low studs are absent (0), two rows of large studs are present (1).

Exemplars: FMNH PR2081 (0), MOR 008 (1).

630. Postorbital, rugose patch that is located caudodorsal to the cornual process, texture, lateral view: subtle (0), coarse (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

631. Postorbital, corner of the laterotemporal fenestra, dorsal margin, lateral fossa, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

632. Postorbital, corner of the laterotemporal fenestra, fossa, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

633. Postorbital, laterotemporal fenestra, spur above the joint surface for the jugal, medial view: absent (0), present (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

634. Postorbital, depth of the squamosal process, lateral view (Carr, 1999): shallow (0), deep (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Ontogeny: Character first described in Carr (1999); transition from slender to deep.

635. Postorbital, squamosal process, dorsal margin, orientation, lateral view: dorsal margin extends horizontally or at a low caudoventral angle (0), extends caudoventrally at a steep angle (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

636. Postorbital, squamosal process, lower edge, lateral view: only the distal half of the process overlaps the squamosal (0), the entire ventral edge overlaps the squamosal (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5117 (1).

637. Postorbital, squamosal process, base, form, ventral view: narrow convex ridge (0); wide and shelf-like, bounded laterally by a ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

638. Postorbital, squamosal process, lateral groove, extent, ventral view: shallow groove limited distally (0), groove is deep and extends rostrally to the base of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

639. Postorbital, joint surface for the squamosal, height of the medial flange, lateral view: exceeds the height of the lateral flange (0), lateral flange is taller than the medial flange for its entire length (1), medial flange is absent (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

Note 1: This binary formulation is identical to this character: *Joint surface for the squamosal and the smooth medial surface: reaches the dorsal margin of the base (0), does not reach the dorsal margin (1).*

Note 2: This binary formulation also matches this character: *Joint surface for the squamosal, exposure, medial view: minimally exposed, faces dorsally (0); deeply exposed, faces medially (1).*

640. Postorbital, joint surface for the squamosal, medial process and notch, presence: process is tall and notch is present (0), low spur, shallow notch (1), low ridge or absent (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5117 (1), MOR 555 (2).

641. Postorbital, joint surface for the squamosal, extent of groove, ventral view: limited to the distal third of the process (0), extends rostral to the laterotemporal fenestra (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

642. Postorbital, joint surface for the squamosal, texture, medial view: fine and shallow longitudinal ridges (0), deep and numerous longitudinal ridges (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

643. Postorbital, squamosal process, medial surface, nonjoint surface from the body, form, medial view: extends caudally across base of process to the dorsal margin (0), pinches out a short distance behind the body (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

644. Postorbital, caudal wall of the orbit, form, rostral view: distinctly concave (0); gently concave, flat, or convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

645. Postorbital, orbit margin, shape, lateral view: shallowly concave (0), deeply concave (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Note: This character is included to test the hypothesis of whether or not it is homologous to a large and deep subocular process.

Result: Character 645 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

646. Postorbital, orbit margin, position of foramen in margin, rostral view: pierces the lateral edge and extends into the lateral surface (0), a short distance medial to lateral margin (1), far medial to lateral margin (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

647. Postorbital, jugal ramus, margin of orbital fenestra below base of the laterosphenoid process, lateral view: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

648. Postorbital, jugal ramus, distal end, shape, ventral view: wedge-shaped to fit into groove in jugal (0), flattened or dilated to receive the wide and coarse surface of the jugal (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

649. Postorbital, jugal ramus, rostral and caudal margins, lateral view: both margins are concave (0), rostral margin is concave and the caudal margin is convex (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

650. Postorbital, jugal ramus, rostral and caudal margins, converge or diverge distally (=ventrally), lateral view: converge (0), diverge (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

651. Postorbital, jugal ramus, width of ramus, caudal view: narrow and thins distally (0), wide and parallel-sided (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

652. Postorbital, joint surface for the jugal, medial view: discrete facet, dorsal extent does not contact medial fossa (0); dorsal extent fades onto medial surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

653. Postorbital, joint surface for the jugal, exposure, medial view: exposed in midregion or only distal end extends out of view (0), entirely exposed medially (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

654. Postorbital, joint surface for the jugal, texture, medial view: coarse throughout (0), coarse distally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

655. Postorbital, jugal ramus, joint surface for the jugal, orientation, caudal view: entire joint surface faces caudally (0); ventral half faces caudally, dorsal half wraps onto medial surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

656. Postorbital, change in direction between the rostral margin of the laterotemporal fenestra and the contact with the jugal, lateral view: abrupt (0), indistinct (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

657. Postorbital, jugal ramus, depth of region below subocular flange, lateral view: shallow, less than the depth of the orbital region (0); as deep or greater than the depth of the orbital fenestra (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

658. Postorbital, subocular process, rostrocaudal length, lateral view: does not extend past the base of the frontal process (0), nearly as long as the frontal process (1), as long as or longer than the frontal process (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FAMNH PR2081 (2).

659. Postorbital, subocular process, presence and size, lateral view (Carr, 1999): very small (0), prominent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

660. Postorbital, jugal ramus, width of ridge that extends ventrally from the laterosphenoid process, ventromedial view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

SQUAMOSAL (58 characters)

661. Squamosal, quadratojugal ramus, dorsal half, orientation, rostral view: extends dorsolaterally (0), extends dorsomedially (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

662. Squamosal, quadratojugal process, distal end, texture, lateral view: small ridges (0), coarsened by massive ridges (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

663. Squamosal, quadratojugal process, proximal end, orientation, lateral view: extends horizontally (0), extends rostr dorsally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

664. Squamosal, quadratojugal process, dorsal end, long axis orientation, rostral view: effectively vertical, slight ventrolateral curvature (0); distinct twist such that the nonjoint surface extends sharply ventrolaterally to culminate in a laterally-jutting ridge (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

665. Squamosal, joint surface for the quadratojugal, rostral part, extent, lateral view: covers almost the entire depth, except dorsally (0); covers the ventral half of the process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

666. Squamosal, joint surface for the quadratojugal, rostral part, extent on tip of the process, lateral view: covers entire tip of the process (0), tip is not covered (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

667. Squamosal, joint surface for the quadratojugal, rostral part, shape, lateral view: not a deep, scalpel-shaped flange (0); deep, scalpel-shaped flange (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

668. Squamosal, joint surface for the quadratojugal, rostral part, texture, lateral view: mottled texture except at its rostral tip where it is coarsened by distinct ridges (0), coarsened throughout by distinct rostroventrally trending ridges (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

669. Squamosal, joint surface for the quadratojugal, rostral part, dorsal margin, lateral view: bounded by a shallow ridge (0), dorsal margin blends with the lateral surface of bone (1), deeply concave (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

670. Squamosal, joint surface for the quadratojugal, slot in dorsal margin, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

671. Squamosal, quadratojugal process, ventral margin, concavity, presence, lateral view: present and divides the joint surface into rostral and caudal parts (0), absent and the joint surface is continuous (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

672. Squamosal, proximal joint surface for the quadratojugal, form, medial view: distinct (0), indistinct (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

673. Squamosal, proximal joint surface for the quadratojugal, ventrally-facing groove, presence, ventral view: absent (0); a deeply excavated, rostrocaudally extending groove scours the ventral surface of the proximal end of the quadratojugal process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

674. Squamosal, dorsal surface, medial extent, medial view: does not extend medially (0), extends medially and forms a shelf over the medial joint surface (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

675. Squamosal, caudal process, pneumaticity: apneumatic (0), pneumatic (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

676. Squamosal, caudal process, direction, dorsal view: extends caudally (0), extends caudomedially (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

677. Squamosal, caudal process, texture, lateral view: lightly rugose (0), coarsely rugose (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

678. Squamosal, quadratojugal process, base, pneumatization, presence: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

679. Squamosal, medial process, inflation, medial view: not inflated (0), inflated (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

680. Squamosal, medial process, orientation, medial view: extends rostr dorsally at a low angle (0), extends rostr dorsally at a steep angle (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

681. Squamosal, medial process, ventral margin of base, medial view: distinctly dorsally concave (0), shallowly concave (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

682. Squamosal, medial process, rostral half of joint surface, orientation, dorsal view: faces more dorsomedially than medially (0), faces more medially than mediodorsally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

683. Squamosal, medial process, dorsal base, medial view: at same level and continuous with the margin of the dorsotemporal fenestra (0), separated by a notch (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

684. Squamosal, medial process, ridge that extends distally along the medial joint surface of the process, medial view: extends caudally to the dorsal margin of the bone far caudal to the rostral margin of the dorsotemporal fenestra (0), short and fades at or a short distance caudal to dorsotemporal fenestra (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

685. Squamosal, bar rostral to pneumatic foramen, inflation, ventral view: not inflated and rostrocaudally short (0), inflated and rostrocaudally long (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

686. Squamosal, strut lateral to foramen, form, ventral view: low and wide (0), narrow and deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

687. Squamosal, strut medial to foramen, form, ventral view: deep and narrow (0), wide and convex (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

688. Squamosal, medial margin, form, dorsal view: deeply concave (0), shallowly concave or convex (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

689. Squamosal, shelf caudal to pneumatic foramen, presence, ventral view: shelf is present (0), shelf is absent (i.e., inflated) (1).

Exemplars: FMNH PR2081 (0), CM 9380 (1).

Note: Juveniles lacking a foramen are coded as inapplicable (“?”).

690. Squamosal, pneumatic foramen, caudal extent, position, ventral view: foramen is rostral to the level of the quadrate notch (0), foramen extends toward the level of the quadrate notch (1).

Exemplars: MOR 1125 (0), CM 9380 (1).

691. Squamosal, muscular fossa at junction of postorbital and quadratojugal rami, exposure, lateral view: exposed on quadratojugal ramus only (0), exposed in lateral view on the postorbital process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: This character is equivalent to *Squamosal, postorbital process, lateroventral edge, extent onto lateral surface above a muscular fossa, lateral and ventral views: fossa is limited caudally* (0), *fossa extends rostrally* (1).

692. Squamosal, muscular fossa at junction of postorbital and quadratojugal rami, dorsal margin, lateral view: bounded dorsally by a ventrally-extending ridge that extends to the caudal end of the fossa (0), ridge fades before reaching fossa (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

693. Squamosal, joint surface for the paroccipital process, dorsoventral height over the quadrate cotyle, medial view: dorsoventrally shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

694. Squamosal, joint surface for the otoccipital above the quadrate cotyle, form, medial view: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

695. Squamosal, joint surface for the otoccipital, connection to the joint surface for the paroccipital process, medial view: separate (0), confluent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

696. Squamosal, joint surface for the prootic, position, medial view: limited to distal end of the medial process, flattens the ventral surface (0); excavates the medioventral surface and extends ventrally as a low flange (1); excavates the medioventral surface and extends ventrally as a deep flange (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

697. Squamosal, joint surface for the quadrate opposite the medial bar, medial view: concave (0), filled with a convex pad of porous bone (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

698. Squamosal, quadrate notch, mediolateral position, dorsal view: closely approaches the lateral edge of the medial joint surface (0), displaced far medially from the lateral margin of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

699. Squamosal, quadrate cotyle, rostral surface, ventral view: concave (0); medial strut is so swollen that it extends caudally, making the rostral surface of the cotyle convex (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

700. Squamosal, quadrate cotyle, lateral notch, lateral view: opens ventrally (0), opens caudoventrally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

701. Squamosal, quadrate cotyle, texture, medial view: ridges are absent from the cotyle (0), low ridges extend into the cotyle (1), coarse ridges extend into the cotyle (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

702. Squamosal, flange along rostral margin of dorsotemporal fenestra, presence, rostral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

703. Squamosal, dorsotemporal fenestra, rostral margin, lateral half, dorsal view: straight, extends rostromedially (0); angular, extends rostromedially at a low (parasagittal) angle, then abruptly at a higher (rostrolateral) angle (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

704. Squamosal, dorsotemporal fenestra, depth of medial notch, dorsal view: not deeply notched (0), notched deeply (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

705. Squamosal, nuchal crest surface (=dorsotemporal fossa), caudolateral edge, prominence of bounding ridge, dorsal view: low, but extends to the caudal process (0); fades before reaching the caudal process (1).

Exemplars: BMR 2002.4.1 (0), CM 9380 (1).

706. Squamosal, dorsotemporal fossa, ridge that extends caudally from the rostral end of the medial process, caudal extent, dorsal view: extends to the caudal process (0), fades before reaching the caudal process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

707. Squamosal, dorsotemporal fossa, lateral margin, dorsal view: does not reach the lateral edge of the dorsal postorbital process (0), reaches the lateral margin of the process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

708. Squamosal, postorbital process, flange from lateroventral margin of process below caudal end of joint surface for postorbital, presence, lateral view: present (0); absent, lateroventral margin extends laterally above laterotemporal fossa (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

709. Squamosal, postorbital process, flange from the lateroventral margin of the process below the caudal end of the joint surface for the postorbital, extent, ventral view: starts distal to the caudal corner of laterotemporal fenestra, flange and lateral strut are separated by a shallow groove (0); flange and groove extends to the caudal end of the fenestra (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

710. Squamosal, ventral postorbital process, flange that bounds the laterotemporal fossa laterally, form, lateral and ventral views: divided into rostral and caudal parts by a notch (0); notch absent, a continuous flange (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

711. Squamosal, ventral postorbital process, orientation of lateral ridge, ventral view: extends laterally more than ventrally (0), extends ventrally more than laterally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

712. Squamosal, lateral ridge, width along lateroventral flange, ventral view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

713. Squamosal, dorsal postorbital process, joint surface for the postorbital, rostradorsal region, lateral view: does not occupy the rostradorsal region (0), occupies the region as a long convexity (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

714. Squamosal, caudal end of the joint surface for the postorbital, proximity to the dorsal margin of the dorsal postorbital process, lateral view: closely approaches dorsal margin of dorsal postorbital process (0), does not approach (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

715. Squamosal, dorsal postorbital process, extent of the joint surface for the postorbital onto the process, lateral view: laps onto the ventral margin (0), overlaps the ventral quarter to third of the process (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

716. Squamosal, dorsal postorbital process, depth and angle of its rostradorsal margin, lateral view: long and low (0), short and deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

717. Squamosal, nuchal surface, lateral half, texture, dorsal view: lightly textured (0), coarsely textured (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

718. Squamosal, incorporation into the nuchal crest, presence, caudal view: absent (0), present (1).

Exemplars: CMNH 7541 (0), MOR 008 (1).

Note 1: In the incorporated condition, the dorsomedial corner of the squamosal, when the skull is viewed from behind, nearly touches the lateral edge of the nuchal crest. Also, the coarse texture of the dorsum of the nuchal crest on the parietal continues laterally onto the caudodorsal surface of the squamosal.

Note 2: In caudal view, the distinct, vertical scarring along the caudodorsal surface of the nuchal crest of the parietal continues uninterrupted laterally onto the dorsomedial corner of the squamosal (e.g., MOR 008), indicating its incorporation into the nuchal crest. Snively and Russell (2007) also observed the muscle scars on the squamosal of *T. rex*, and identified them as the insertion for m. complexus; the scars on the parietal were identified as the insertion for m. transversospinalis. These inferences are consistent with the hypothesis that the dorsum of the squamosal forms the lateral segment of the nuchal crest, greatly expanding its surface area. In contrast, Tsuihiji (2010) regards the depressor mandibulae to originate from the squamosal; given the continuity between the muscle scars of the parietal and squamosal in *T. rex*, and the complex route implied by the extreme distance between the squamosal and caudal fossa of the articular, the hypothesis of Snively and Russell (2007) is followed here.

QUADRATOJUGAL (42 characters)

719. Quadratojugal, squamosal process, rostral margin, cleft, depth, lateral and rostral views: absent (0), shallow (1), deep (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1), AMNH FARB 5027 (2).

720. Quadratojugal, squamosal process, rostral margin, medial or lateral view: concave (0), straight to convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

721. Quadratojugal, squamosal process, rostral edge, width, rostral view: narrow (0), wide and flat (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

722. Quadratojugal, squamosal process, dorsal margin, notch, lateral view: deeply notched caudal to a rostradorsal flange (0), notch and flange are very low (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

723. Quadratojugal, squamosal process, squamosal notch, caudal margin, lateral view: steep angle (0), low angle (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

724. Quadratojugal, squamosal process, dorsal margin, process, joint surface for the quadrate, lateral view: tall process with a steep rostral margin between quadrate notch and squamosal process notch, and the joint surface faces caudally and so does not extend into view (0); process is low and caudal half is excavated by the quadrate joint surface that extends into lateral view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

725. Quadratojugal, squamosal process, joint surface for the squamosal, extent, medial view: covers the rostral half of the process (0), extends caudally such that it covers more than the rostral half (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

726. Quadratojugal, squamosal process, joint surface for the squamosal, texture, medial view: low ridges (0), deep grooves and tall ridges (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

727. Quadratojugal, squamosal process, dorsal margin, along the region of the notch, margin, lateral view: smooth arc (0), irregular and coarse (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

728. Quadratojugal, squamosal process, rostral surface, lateral ridge, presence, rostral view: thin ridge along lateral margin is present (0), low and indistinct (1), absent (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1), MOR 555 (2).

729. Quadratojugal, squamosal process, rostradorsal margin, orientation, lateral view: extends rostroventrally at a relatively steep angle (0), extends rostroventrally at a relatively shallow angle or horizontally (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1).

730. Quadratojugal, squamosal process, laterotemporal fossa, exposure, lateral view: not exposed (0), exposed (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

731. Quadratojugal, jugal process, depth, lateral view: shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

732. Quadratojugal, jugal process, dorsal and ventral margins, orientation, medial or lateral view: parallel proximally, converge distally (0); margins diverge proximally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

733. Quadratojugal, jugal ramus, dorsal margin, position on base of shaft, rostradorsal view: extends to the lateral edge of the shaft (0), extends up the midwidth of the shaft (1), extends to the medial edge of the shaft (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1), FMNH PR2081 (2).

734. Quadratojugal, jugal ramus, lateral surface between the base of the jugal process and ventral quadrate process, fossa, presence and depth, lateral view: present but shallow or absent (0); deep, secured by a lateral ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

735. Quadratojugal, jugal ramus, ventral margin, form, lateral view: horizontal or straight (0), concave (1), convex (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1), FMNH PR2081 (2).

736. Quadratojugal, jugal ramus, ventral margin, distal half or third, orientation, medial or lateral view: straight, does not deviate from the proximal end (0), extends rostr dorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

737. Quadratojugal, squamosal process, ridge, mediolateral width, rostral view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

738. Quadratojugal, lateral fossa, rostral ridge, lateral view: extends caudoventrally below midheight (0), fades at midheight (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

739. Quadratojugal, rostral ridge, distinctiveness of proximal extent, lateral view: blends with lateral surface proximally (0), distinct and wide proximally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

740. Quadratojugal, dorsal quadrate process, caudal margin, notch at midheight, medial view: notch absent (0), notch present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

741. Quadratojugal, dorsal joint surface for the quadrate, texture and rostrocaudal width, medial view: narrow and smooth (0), wide and coarse (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

742. Quadratojugal, dorsal joint surface for the quadrate, rostral margin, form, medial view: convex (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

743. Quadratojugal, dorsal joint surface for the quadrate, caudal half, form, medial view

A: entire joint surface is smooth (0), entire caudal half is developed into a wide ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

744. Quadratojugal, dorsal joint surface for the quadrate, caudal half, form, medial view B:

not peg-in-socket (0), peg-in-socket (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

745. Quadratojugal, vertical shaft, margin between the quadrate processes, form, medial view: nearly vertical (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

746. Quadratojugal, vertical shaft, margin between the quadrate processes, dorsoventral height, medial view: approaches the depth of the ventral quadrate process (0), shorter than the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

747. Quadratojugal, vertical shaft, position of the medial edge of the caudal margin, medial view: rostral to the lateral edge of the shaft (0), caudal to the lateral edge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

748. Quadratojugal, vertical shaft, waist, minimum rostrocaudal length, lateral view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

749. Quadratojugal, jugal process, depth of the base of the process, lateral view: shallow (0), deep and forms the ventral part of the laterotemporal fenestra such that the margin extends rostroventrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

750. Quadratojugal, mediolateral width of ridge above the joint surface for the ventral quadratojugal process of the jugal, ventral view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

751. Quadratojugal, ventral quadrate process, caudal margin, caudal view: deeply notched (0), notch absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

752. Quadratojugal, ventral quadrate process, dorsal margin, orientation, caudal view: extends caudodorsally (0), caudoventrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

753. Quadratojugal, ventral quadrate process, smooth medial surface between the joint surface for the quadrate and that for the jugal, form, medial view: truncated between the joint surfaces as a triangular platform (0), elaborated into a caudoventrally extending spur (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

754. Quadratojugal, proximal (=caudal) end of the joint surface for the ventral quadratojugal process of the jugal, form, medial view: shallowly excavated groove that faces primarily medially (0), deeply excavated groove that faces ventrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

755. Quadratojugal, ventral quadrate process, dorsal margin of the joint surface for the quadrate, orientation, medial view: extends rostroventrally (0), extends rostradorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

756. Quadratojugal, ventral joint surface for the quadrate, texture and depth, medial view: shallow and coarse (0), pocketed rostradorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

757. Quadratojugal, ventral joint surface for the quadrate, groove rostradorsal to the joint surface, presence, medial view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

758. Quadratojugal, ventral joint surface for the quadrate, proximity to the corner of the laterotemporal fenestra, medial view: closely approaches (0), widely separated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

759. Quadratojugal, ventral quadrate process, horizontal ridge at midheight, presence, lateral view: present (0), absent (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

760. Quadratojugal, ventral quadrate process, caudal surface, fossa, presence, caudolateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

QUADRATE (27 characters)

761. Quadrate, main shaft, caudodorsomedial edge, medial view, form: shallowly concave (0), distinctly concave (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

762. Quadrate, dorsal quadratojugal process, dorsal half, cleft, lateral view: cleft is present (0), homologous region is a wide ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

763. Quadrate, dorsal quadratojugal process, dorsal margin, caudal view: extends dorsomedially to the otic condyle (0), dorsal margin does not reach the top of the otic process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

764. Quadrate, ventral quadratojugal process, ventral margin, with the condyles on a level surface, rostral view: extends at a low angle (less than 10 degrees) laterodorsally (0), marginally steeper (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

765. Quadrate, ventral quadratojugal process, dorsomedial corner of the joint surface, position, caudal view: closely approaches the base of the process (0), widely separated from the base of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

766. Quadrate, ventral quadratojugal process, dorsolateral corner of the joint surface, process, caudal view: coarse, but low rugosity (0); large tooth-shaped process extends caudally from this region (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

767. Quadrate, ventral quadratojugal process, joint surface, texture, caudal view: coarse laterally, but shallow and medially convex (0); coarse, deep and generally concave (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

768. Quadrate, orbital process, joint surface for the pterygoid, depth of caudoventral corner, medial view: deeply inset (0), barely perceptible (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

769. Quadrate, orbital process, lateral strut of the pneumatic foramen, medial view: not in view (0), in view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

770. Quadrate, orbital process, ventral margin of lateral strut of the pneumatic foramen, connection with the main shaft, rostral, lateral and medial views: extends caudoventrally to join shaft above mandibular process (0), extends like a web vertically down rostral surface of process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

771. Quadrate, orbital process, orientation, ventral view in articulated skull: extends more medially than rostrally (0), equally rostral and medial (1), extends more rostrally than medially (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), AMNH FARB 5027 (2).

772. Quadrate, ventral quadratojugal process, dorsal margin, orientation, rostral and caudal views: extends lateroventrally (0), extends laterodorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

773. Quadrate, orbital process, rostral margin, lateral view: extends rostroventrally along a low angle (0), nearly vertical (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

774. Quadrate, pneumatic foramen, size and shape, rostral view: small and teardrop shaped (0); large and wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

775. Quadrate, pneumatic foramen, rostradorsal extent of fossa, medial view: does not extend onto the medial surface of the orbital process (0), extends onto the medial surface of the orbital process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

776. Quadrate, mandibular process, medial edge, fossa, depth, medial view: shallow fossa (0), foramen or large coarse fossa (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

777. Quadrate, mandibular process, orientation, ventral view in articulated skull: low caudomedial angle (0), mediolateral to rostralateral (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

778. Quadrate, lateral mandibular condyle, depth, caudal view: shallower than medial condyle (0), deeper than medial condyle (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

779. Quadrate, lateral mandibular condyle, dorsal margin, projection from shaft, rostral view: entire margin juts out from shaft surface (0), only the medial half is differentiated from the shaft (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

780. Quadrate, medial mandibular condyle, dorsal margin, rostral view: bilobate, a notch separates the lobes (0); differentiation not obvious (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

781. Quadrate, medial mandibular condyle, caudal extent, lateral and medial views: extends caudally behind main shaft (0), does not extend beyond the shaft (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

782. Quadrate, medial mandibular condyle, position relative to the shaft, rostral and medial views: extends medially (0), level with the shaft above it (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

783. Quadrate, mandibular process, longest region of the midpoint of the condylar surface, ventral view: through the lateral half of the medial condyle (0), through the medial half of the lateral condyle (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

784. Quadrate, mandibular process, caudal margin of lateral half of process, form, dorsal view: deeply concave (0), shallowly concave to gently convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

785. Quadrate, dorsal margin of the dorsal quadratojugal process, width, caudal view: narrow, medial to the ventral tip of the process (0); wide, reaches or exceeds the level of the ventral tip of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

786. Quadrate, otic process, differentiation into lateral and medial condyles, dorsal view: not differentiated into a pair of condyles (0), differentiated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

VOMER (15 characters)

787. Vomer, overall width, dorsal and ventral views: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

788. Vomer, rostral process, ventral surface, form, mediolateral cross section, ventral view (Molnar, 1991): convex (0); rostral half is convex, caudal half is concave or the opposite (1).
Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

789. Vomer, rostral process, caudolateral margin, length: short (0), long (1).
Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

790. Vomer, rostral process, tip, condition, dorsal and ventral views (Witmer and Ridgley, 2009): bifurcated (0), not bifurcated (1).
Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

791. Vomer, rostral process, orientation, lateral view: extends horizontally from stem (0), extends rostradorsally from stem (1).
Exemplars: CMNH 7541 (0), RSM 2523.8 (1).

792. Vomer, ventral keel, deepest point, position, lateral view: below rostral end of the body (0), below the caudal end of the rostral process (1).
Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

793. Vomer, ventral keel, shape, lateral view: angular (0), convex (1).
Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

794. Vomer, ventral keel, position relative to maxillary teeth, ventral view: eighth tooth (0), ninth tooth (1).
Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

795. Vomer, body, dorsal margin, form, lateral view: straight (0), gently concave (1), convex (2).
Exemplars: CMNH 7541 (1), BMRP 2002.4.1 (1), RSM 2523.8 (2).

796. Vomer, body, ventral margin, rostral end of split, lateral view: marked by an angulation (0), angulation is absent (1).
Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

797. Vomer, joint surface for the palatine, caudal half, ventral margin, orientation, lateral view: horizontal (0), rostradorsal (1).
Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

798. Vomer, joint surface for the palatine, collar-like ridge along rostradorsally extending rostral half of the joint surface, presence, lateral and caudodorsal views: present (0), absent (1).
Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

799. Vomer, joint surface for the palatine, depth, dorsal view: deeply inset such that is secured along its lateral edge by a deep groove flanked by a tall lateral ridge (0), shallowly inset such that it is not secured by a deep groove (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

800. Vomer, intervomer suture, closure, ventral view: closed (0), open (1).

Exemplars: BMRP 2002.4.1 (0), MOR 3044 (1).

PALATINE (44 characters)

801. Palatine, body of bone, inflation, all views (Carr, 1999): not inflated (0), inflated (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Ontogeny: Character first described in Carr (1999); transition from laterally compressed to inflated (*A. libratus*).

802. Palatine, body of the bone, inflation, caudal view: inflated, but grooves absent (0); inflated, producing a groove between the body of the bone and the pterygoid process or the caudolateral process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

803. Palatine, body of the bone, hump, presence, lateral, dorsal, and medial views: absent (0), rostromedial swelling present (1), dorsal swelling present (2). **ORDERED**

Exemplars: CMNH 7541 (0), UWBM 99000 (1), MOR 555 (2).

804. Palatine, body of the bone, hump, size: small, groove between hump and dorsolateral process and does not interrupt the dorsal margin (0); large, grooves between hump and the dorsolateral and dorsal processes, and prominent (1).

Exemplars: MOR 1125 (0), AMNH FARB 5027 (1).

805. Palatine, vomeropterygoid ramus, rostral margin, position, lateral view: caudal, a short distance ahead of caudal margin of rostral recess (0); rostrally ahead of the rostral recess (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

806. Palatine, vomeropterygoid ramus, texture, lateral view: smooth (0); coarsened by multiple, wrinkle-like and rostroventrally trending ridges and grooves (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

807. Palatine, dorsolateral process, base, dorsoventral height relative to the maxillary process, lateral view: base is shallower than that of the maxillary process (0), base is deeper than that of the maxillary process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

808. Palatine, dorsolateral process, base, dorsal and ventral margins, orientation, lateral view: parallel (0), margins converge caudally (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

809. Palatine, joint surface of the dorsolateral ramus, length, lateral view: rostrocaudally elongate (0), dorsoventrally deeper than long (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

810. Palatine, dorsolateral process, joint surface for the lacrimal, rostradorsal margin, lateral view: delimited by a ridge (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

811. Palatine, dorsolateral process, form, caudolateral view: process is concave (0); ventral half is concave, dorsal half is convex (1); base is convex (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 555 (2).

812. Palatine, dorsolateral process, dorsal and ventral processes, orientation, dorsal view: extend caudolaterally, and they are parallel with each other (0), dorsal process extends laterally relative to the ventral process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

813. Palatine, dorsolateral process, divergence from the pterygoid process, dorsal view: diverge at a low angle 45 degrees or less, not widely separated, deep acute curve (0); diverge at an angle close to 45 degrees or greater, widely separated by a concave curve (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

814. Palatine, dorsolateral process, notch in caudal margin, size, lateral view: small notch (0); deep notch, separates the dorsal process into two subsidiary processes, giving it the appearance of a 'fish-tail' (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

815. Palatine, dorsal surface between the dorsolateral and pterygoid processes, dorsal view: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

816. Palatine, rostral pneumatic recess, caudoventral corner, absorption, lateral view: a deep fossa that has a distinct boundary (0), absorbed and has an indistinct caudoventral boundary (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: This character might be homologous to that of character 817, and it is included here to test that hypothesis.

Result: Characters 816 and 817 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

817. Palatine, rostral pneumatic recess, breach of lateroventral margin, lateral view: does not breach such that it is bounded by a distinct ridge (0); recess extends caudoventrally as a fossa, excavating the surface caudoventral to itself and removing the ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Note: This character might be homologous to that of character 816, and it is included here to test that hypothesis.

Result: Characters 816 and 817 were not optimized unambiguously on the ontogram; the hypothesis is unresolved.

818. Palatine, rostral pneumatic recess, septa on medial wall, lateral view (Carr, 1999): absent (0); low and wide ridge extends dorsally from the floor of the recess, or short thin ridge extends ventrally from the rostral end of the recess, wide recess caudal to this (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Ontogeny: The presence of septa was first described in Carr (1999) for *A. libratus*.

819. Palatine, rostral pneumatic recess, distinctiveness, lateral view: distinct (0), indistinct (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

820. Palatine, rostral pneumatic recess, rostral extent, lateral view: extends distally along the maxillary process (0), extends a short distance along the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

821. Palatine, relative depth of pneumatic recesses, lateral view: caudal recess is the same height as the rostral recess (0), caudal recess is deeper than rostral recess (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

822. Palatine, relative length of pneumatic recesses, lateral view: caudal recess is longest (0), rostral recess is longest (1), recesses are the same length (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), MOR 555 (2).

823. Palatine, caudal pneumatic recess, dorsal extent relative to the maxillary process, lateral view: does not extend above the dorsal margin of the base of the maxillary process (0), extends above the level of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

824. Palatine, caudal pneumatic recess, ratio of length to depth, lateral view: longer than deep (0), at least as long as deep (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

825. Palatine, caudal pneumatic recess, dorsal margin, orientation, lateral view: extends rostr dorsally (0), extends rostroventrally (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

826. Palatine, caudal pneumatic recess, shape, lateral view: small and teardrop-shaped (0), large and angular (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

827. Palatine, caudal pneumatic recess, ventral margin relative to that of the rostral pneumatic recess, lateral view: same level (0), dorsal to ventral margin of the rostral recess (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

828. Palatine, accessory pneumatic foramina, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

Note: This character is included to test the hypothesis that the holes might be lesions.

829. Palatine, choanal process, height, lateral and ventral views (Carr, 1999): dorsoventrally shallow, does not extend down vomeropterygoid ramus (0); deep, extends a short distance down the ramus (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Ontogeny: Character first described in Carr (1999); transition from shallow to deep (*A. libratus*).

830. Palatine, choanal process, length, lateral view: long (0), short (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

831. Palatine, choanal process, joint surface for the palatine, ventral extent, medial view: does not extend below the level of the process (0), extends below the level of the ventral margin of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

832. Palatine, choanal process, joint surface for the palatine, texture, medial view: lightly textured surface (0), deeply excavated and coarse (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

833. Palatine, caudal choanal process, length: short (0), long (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

834. Palatine, dorsal process and body of the bone, flange, presence, lateral view: absent (0), present (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

835. Palatine, joint surface for the maxilla of the maxillary process, dorsoventral height, lateral view: dorsoventrally shallow (0); deep, several times deeper than the nonjoint surface above it (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

836. Palatine, joint surface for the maxilla ventral to the caudal pneumatic foramen, separation as a lateral process, presence, dorsal view: is not an independent process (0), extends ventrolaterally and is delimited rostrally and caudally by notches (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

Note: This corresponds to the “triradiate” and “tetroradiate” conditions of Holtz (2001); variant of character 109 of Carrano et al. (2012).

837. Palatine, joint surface for the maxilla, medioventral margin, extent, ventral view: fades below the lateral flange (0), does not fade and extends to the ventral margin of the caudolateral process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

838. Palatine, lateral flange, position, lateral view: behind the caudal margin of the caudal pneumatic recess (0), below the recess (1), at rostral end or ahead of the recess (2). **ORDERED Exemplars:** BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

839. Palatine, lateral flange, lateroventral edge, orientation, lateral view: does not extend ventrally as a flange (0), extends ventrally and caudally as a low or deep flange that deepens the joint surface it carries (1).
Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

840. Palatine, joint surface for the pterygoid, proximal position, ventral view: positioned distal to the base of the process (0); reaches the base of the process dorsally, approaches it ventrally (1).
Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

841. Palatine, pterygoid process, joint surface for the pterygoid, texture: lightly textured surface (0), deeply excavated and coarse (1).
Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

842. Palatine, pterygoid process, joint surface for the pterygoid, ridges, prominence and position: low and wide below midheight of the joint surface, dorsal ridge is present (0); ridge is prominent and close to the ventral margin of the process, dorsal ridge is close to dorsal margin (1).
Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

843. Palatine, pterygoid process, ridge that extends rostrally from the joint surface, form, medioventral view: coarse ridge extends rostroventrally above the midheight of the joint surface (0), low and large burr is present, no associated ridge-like scars (1), low and large burr is ahead of the upper half of the joint surface and a long coarse scar extends rostroventrally from it (2).
ORDERED Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 555 (2).
Note: This is equivalent to the tuberosities rostral to the pterygoid of Brochu (2003).

ECTOPTERYGOID (27 characters)

844. Ectopterygoid, ridge along pterygoid and jugal processes that extends laterally from the slot-like dorsal pterygoid contact, presence, dorsal view: present (0); absent - i.e., the rostromedial region is inflated, obliterating the ridge (1).
Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

845. Ectopterygoid, jugal process, inflation, caudal view (Carr, 1999): not inflated (0), inflated (1).
Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Ontogeny: This character was described in Carr (1999) for *A. libratus*, *D. torosus*, and *T. rex*.

846. Ectopterygoid, jugal process, ridge along the caudal surface of the process, position, caudal view: extends dorsolaterally toward dorsal edge of bone (0), toward ventral edge (1).
Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

847. Ectopterygoid, jugal process, ridge medial to jugal flange, ventral view: indistinct (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

848. Ectopterygoid, jugal process, ridge medial to jugal flange, orientation, medial view: extends dorsolaterally to the dorsal margin of the process (0), extends along the ventral margin of the process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

849. Ectopterygoid, jugal process, distal end curvature, dorsal view: not curved (0), curved (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

850. Ectopterygoid, jugal process, region above the joint surface for the jugal, inflation, rostral view: does not extend laterally over joint surface (0), extends laterally over joint surface (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

851. Ectopterygoid, joint surface for the jugal, orientation when lying flat, ventral view: faces dorsolaterally and so is not in view (0), faces ventrolaterally and so is in view (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

852. Ectopterygoid, joint surface for the jugal, proximodorsal part, form, lateral view: flat (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

853. Ectopterygoid, pneumatic recess, caudal end delimitation, ventral view: not delimited by a ridge (0); delimited by a ridge, which gives the recess a continuous and distinct outline (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

854. Ectopterygoid, pneumatic recess, rostral end of the recess, position, ventral view: close to medial edge of bone (0), far lateral to the medial edge of bone (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

855. Ectopterygoid, pneumatic recess, fossa next to rostral end of recess, presence, ventral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

856. Ectopterygoid, pneumatic sinus, ceiling, laterally-extending ridge, presence and size, medial view: ridge is absent (0), ridge is present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

857. Ectopterygoid, caudolateral process, pneumatic fossa, accessory fossae: absent (0), present and in ventral margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

858. Ectopterygoid, ventral joint surface for the pterygoid, form, medial and ventral views: medially facing slot (0); wide and flat joint surface that widens rostrally over the ventral surface of the bone (1); wide and grooved, widens rostrally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1), LACM 23844 (2).

859. Ectopterygoid, caudal process, muscle attachment surface, extent and size, rostromedial view (Carr, 1999): makes a swelling along the caudodorsal surface (0), is grossly developed and makes a ridge along the caudodorsal edge (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus*, *D. torosus*, and *T. rex*.

860. Ectopterygoid, caudal muscle attachment surface, exposure, ventral view (Carr, 1999): marginally exposed along caudolateral process (0), widely exposed owing to inflation (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus*, *D. torosus*, and *T. rex*.

861. Ectopterygoid, caudal process, width, ventral and dorsal views: widens before tapering to a point (0), does not widen before tapering (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

862. Ectopterygoid, tip of the caudal process, form, caudal view: blunt (0), pointed shallow tip distal to the grossly expanded muscle attachment surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

863. Ectopterygoid, tip of caudal process, orientation with joint surface for the jugal facing laterally, ventral view: points caudolaterally (0), caudomedially (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: The tip in the juvenile condition does not jut *caudolaterally*, but is in line with the lateral edge of the process; in the adult condition the tip does point *caudomedially* such that it juts at an angle away from the lateral edge of the process.

864. Ectopterygoid, caudal process, inflation, all views: not inflated (0), inflated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

865. Ectopterygoid, caudal process, joint surface for the pterygoid on the dorsal surface, depth, dorsal view: shallowly excavated into the process (0), deeply excavated (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

866. Ectopterygoid, caudal process, joint surface for the pterygoid on the dorsal surface, proximity to the caudal nonjoint margin of the process, dorsal view: does not approach the caudolateral margin of the proximal end of the process (0), approaches or reaches the caudolateral margin of the process proximally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

867. Ectopterygoid, caudal process, caudoventral surface next to recess, pneumatic excavation, ventral view: absent, surface is flat (0); present, but shallowly concave (1); present, deeply concave (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 555 (2).

868. Ectopterygoid, caudal process, separation from medial edge of the bone, depth of notch, dorsal and ventral views: notch is present and deep (0), notch is present and shallow (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

869. Ectopterygoid, dorsal pterygoid process, orientation, rostral view: extends mediodorsally at a low angle (0), steep angle (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

870. Ectopterygoid, dorsal joint surface for the pterygoid, form, dorsal view: pterygoid is received in a groove (0), groove is absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

PTERYGOID (2 characters)

871. Pterygoid, main body of the bone, medial margin in ventromedial view: extends caudolaterally as a ridge to the midwidth of the caudal margin of the body of the bone (0); ridge extends to medial half of caudal end of the bone - i.e., stays at medial edge of bone (1).

Exemplars: MOR 1125 (0), AMNH FARB 5117 (1).

872. Pterygoid, main body of the bone, ridge of medial margin in ventromedial view, distal (caudal) extent: reaches the caudal end of the bone (0), fades before reaching the caudal end of the bone (1).

Exemplars: MOR 1125 (0), AMNH FARB 5117 (1).

EPIPTERYGOID (9 characters)

873. Epipterygoid, laterosphenoid process, width, lateral view: narrow (0); wide, especially toward the leading edge of the bone, where it forms a low vertical crest (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

874. Epipterygoid, dorsal process, medial joint surface, exposure, lateral view: concealed in lateral view (0), exposed in lateral view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

875. Epipterygoid, caudal edge, deviation, caudal view: deviates lateroventrally at abrupt angle at lower third of bone (0), deviation is less abrupt (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

876. Epipterygoid, rostral margin of the ventral paddle-like region, lateral view: does not extend laterally as a flange (0), extends laterally as a flange (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

877. Epipterygoid, rostral margin above the ventral process, lateral view: concave (0), gently concave or convex (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

878. Epipterygoid, rostral margin, extent of the flattened rostral surface, rostral view: upper quarter to third is flat (0), over a third to one-half bone height is flattened (1), entire surface is flat (2).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

879. Epipterygoid, rostroventral margin, lateral and rostral views: truncated and extends caudoventrally along a low angle and leading edge is narrow and bladelikey (0), region is not truncated and leading margin is wide and flat (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

880. Epipterygoid, dorsal process, caudal margin, form, medial view: the medial surface along the caudal margin of the process is convex in vertical and horizontal sections (0), a low ridge is present along the caudal edge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

881. Epipterygoid, dorsal process, rostrocaudal length, lateral view: narrow such that it is separated from the ventral process by a subtle ‘waist’ (0); wide such that the ventral process grades into the dorsal process, which tapers as it extends caudodorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 555 (1).

FRONTAL (68 characters)

882. Frontal, proportions of apposed bones, dorsal view: long and narrow (as long as wide) (0), short and wide (wider than long) (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Note: Not a repeat of shape of apposed bones (character 83), which emphasizes the form of the nasal process and the body of the bone.

883. Frontal, nasal ramus, ventral surface, fossa at caudal end of airway, depth, ventral view: shallow (0), deep (1).

Exemplars: DDM 344.1 (0), MOR 555 (1).

Note: The caudal end of the airway is divided by a low ridge that divides it into lateral and medial halves; the character is described here in reference to the lateral half of the airway. The surface is flat and horizontally oriented in the *shallow* condition, whereas it flares laterodorsally in the *deep* condition.

884. Frontal, nasal ramus, ventral surface, ridge that separates surface into lateral and medial halves, form, ventral view: low and fades as it extends rostromedially along a straight line (0), distinct and curves from caudolaterally to medially to rostromedially (1).

Exemplars: DDM 344.1 (0), MOR 1125 (1).

885. Frontal, nasal ramus, ventral surface, rostral end of airway, mediolateral depth, form, ventral view: rostral end of airway is nearly flat (0), rostral end of airway is subtly concave in mediolateral section (1), rostral end of the airway is deeply concave (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1125 (1), MOR 2822 (2).

886. Frontal, nasal ramus, joint surface for the mesethmoid, form, ventral view: low, narrow, and subtle ridge that fades rostrally after a short distance along the midline (0); proximally wide and distinct, but low ridge that fades before reaching the rostral end of the nasal ramus (1); distinct, platform-like ridge proximally that extends to the rostral tip of the nasal ramus as a deep and narrow, or low, ridge with a distinct lateral edge (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

887. Frontal, endocranial surface, ridge that separates the cerebral fossa from the olfactory fossa, ventral view: distinct ridge that extends from rostromedially to caudomedially (0), ridge is obliterated by the deep condition of the bone (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

888. Frontal, endocranial surface, cerebral fossa, depth, ventral view: an extremely deep, rostromedially pocketed concavity (0); subtly concave (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

889. Frontal, endocranial surface, cerebral area, size, ventral view: massive, occupies the caudomedial quadrant of the bone and nearly a third of its rostrocaudal length (0); reduced to a small surface at the extreme caudomedial corner of the bone, the fossa is effectively displaced off the frontal and (presumably) onto the parietal (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

890. Frontal, endocranial surface, cerebral fossa, caudolateral end, shape: triangular, tapers caudolaterally to a point (0); rectangular, expands as it extends caudolaterally (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

891. Frontal, endocranial surface, caudomedial margin, form, ventral view: region between the inflection between the interfrontal suture and the frontoparietal suture, and the caudolateral corner of the endocranial surface, is convex and broadly triangular (0); the corresponding surface is subtly concave (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

892. Frontal, cranial crest, rostromedial segment, transition to ventral surface of the bone, rostral view: the rostral surface of the crest and the ceiling of the airway grade into each other along a broad curve (0); structures are separated by a distinct, but shallow groove (1); separated by a deep groove (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

893. Frontal, cranial crest, joint surface for the prefrontal, ventral half, form, rostral view: ventral margin is deeply notched by a distinct groove that extends ventrolaterally from the center of the joint surface and the joint surface in this region is smooth (0); the ventral margin is not

notched, whereas the joint surface is coarsened along its ventral edge by massive, ventrolaterally extending ridges and slots (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

894. Frontal, cranial crest, joint surface for the prefrontal, orientation, rostral view: deepest part of the slot-like joint surface extends ventrolaterally (0), slot extends vertically (1).

Exemplars: DDM 344.1 (0), MOR 1131 (1).

895. Frontal, cranial crest, joint surface for the lacrimal, form, rostral view: lateral notch is present, rostroventral surface is smooth to lightly coarse (0); notch is absent, rostroventral surface is coarsened by massive, rostrolaterally-extending ridges (1); notch is absent, joint surface is coarse (ridges are absent), and the joint surface is continuous with that of the prefrontal along its lateral half (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 2822 (1), MOR 980 (2).

896. Frontal, cranial crest, joint surface of the prefrontal and lacrimal, depth, rostral view: the most deeply inset point of the joint surface for the prefrontal is situated far rostral to that of the lacrimal (0), the deepest part of the joint surface for the prefrontal reaches as far caudally as that for the lacrimal (1).

Exemplars: DDM 344.1 (0), MOR 1131 (1).

897. Frontal, cranial crest, joint surface for the prefrontal, caudal wall, orientation, rostral view: extends rostradorsally like a ceiling over the joint surface (0); vertically oriented, flat, rostrally-facing wall, does not overhang the joint surface (1).

Exemplars: DDM 344.1 (0), MOR 1131 (1).

898. Frontal, cranial crest, rostrolateral segment, joint surface for the mesethmoid, form, ventral and rostroventral views: a subtle, ventrally flaring ridge that forms the ventral-most extreme of the cranial crest (0); a rugose, patch-like, and oval facet that flares ventrally as in the preceding state (1); a series of deep sockets separated by thick ridges (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

899. Frontal, cranial crest, form, ventral view: a prominent, ventrally extending ridge that is separated from the orbit ceiling by an indistinct crease (0); effectively incorporated into the ceiling of the frontal, such that it is not a distinct ridge, and it is continuous with the rest of the dorsolaterally extending orbit ceiling (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

900. Frontal, cranial crest, joint surface for the orbitosphenoid, form, ventral and caudoventral view: a single, shallow scour-like groove that excavates the ventromedial surface of the cranial crest that is bounded laterally by a thin ridge (0); a pair of pit-like concavities that face ventrally, where the rostral pit is shallow and small, and the caudal pit is large, narrow, and deep (1); rostral pit is massive and deeply excavated, whereas the caudal pit is smaller and also deeply excavated (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

901. Frontal, cranial crest, joint surface for the laterosphenoid, ventral view: small, coarse joint surface adjacent to that for the orbitosphenoid that coarsely excavates the caudal end of the cranial crest and faces more caudally than ventrally (i.e., nearly directly caudally) (0); massive pedicle-like structure excavated by large, rostromedially extending ridges and slots that faces caudoventrally (slightly more ventrally than caudally) and is separated from the joint surface for the orbitosphenoid by a wide gap (1); massive and pinches out the gap between itself and the joint surface for the orbitosphenoid, coarse pedicle that faces slightly caudoventrally (i.e., nearly directly ventrally) (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

902. Frontal, orbit ceiling, foramina, presence, ventral view: small, round or elliptical foramina penetrate the ceiling (0); absent (1).

Exemplars: LACM 28471 (0), MOR 1131 (1).

903. Frontal, orbit ceiling, orbital notch, ventral extent, ventral view: a deep, rostromedially extending cleft at the lateral margin of the bone, extends caudomedially as a rapidly fading groove across the orbit ceiling that differentiates the cranial crest from the orbit ceiling (0); the notch is expressed as a shallow groove (not a notch) in the ventrolateral edge of the bone and extends as a caudomedially extending, vanishingly shallow groove that subtly separates the cranial crest from the orbit ceiling (1); expressed as a small, dorsolaterally extending depression below the spot where the joint surfaces for the lacrimal and postorbital join, no distinction between the cranial crest and the orbital ceiling is seen (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

904. Frontal, orbital notch, form, dorsal view: shallow, laterally facing notch (0), deep, rostromedially facing notch (1); shallow, subtly rostromedially (faces nearly directly rostrally) facing emargination (2). **ORDERED**

Exemplars: DDM 344.1 (0), MOR 1131 (1), MOR 2822 (2).

905. Frontal, frontal joint surface, form, medial view: rostral and caudal regions sharply differentiated, where the caudal region extends distinctly medially (0); rostral and caudal parts of the joint surface are on the same mediolateral plane (i.e. the joint surface is flat, aside from the ridges and grooves that coarsen it) (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

906. Frontal, frontal joint surface, rostradorsal region, form, medial view: rostradorsal corner is not abruptly truncated by the joint surface for the medial process of the nasal (0), corner is abruptly truncated by the joint surface (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

907. Frontal, frontal joint surface, caudadorsal quadrant, form, medial view: dominated by the widely exposed joint surface for the parietal, represented by a pair of parallel grooves (0); dominated by the joint surface for the frontal, where that for the parietal is limited to a single caudadorsal groove that is marginally in view (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

908. Frontal, medial surface, sagittal foramen, position and extent, medial view: extends for a short distance caudoventrally before it is pinched out far below the dorsal margin of the bone (0), extends caudoventrally below the ridge that forms the sagittal crest (i.e., extend below the dorsum of the bone) and reaches the caudal edge of the bone (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

909. Frontal, medial surface, dorsoventrally deepest point, location, medial view: caudal, at the rostral end of the ridge that separates the olfactory and cerebral fossae (0); rostral, at the rostral extreme of the dorsotemporal fossa (1).

Exemplars: DDM 344.1 (0), MOR 1131 (1).

910. Frontal, joint surface for the lateral frontal process of the nasal, form, dorsal view: flat facet (0), deep groove (1), absent owing to subduction of process (2). **ORDERED**

Exemplars: LACM 28471 (0), MOR 555 (1), UWBM 99000 (2).

911. Frontal, joint surface for the medial frontal process of the nasal, length, dorsal view: short, where it stops ahead of the joint surface for the prefrontal or reaches the rostral end of the joint surface for the prefrontal, joint surface does not extend as far caudally as that for the lateral frontal process (0); long, where it reaches caudally past the rostral end of the joint surface for the prefrontal, extends as far caudally as that for the lateral frontal process (1).

Exemplars: LACM 28471 (0), MOR 980 (1).

912. Frontal, prefrontonasal process, presence, dorsal view: absent (0), present (1).

Exemplars: DDM 344.1 (0), MOR 1125 (1).

Note: The prefrontonasal process is a stout spur that separates the caudal tip of the lateral frontal process of the nasal from the medial edge of the prefrontal.

913. Frontal, joint surface for the prefrontal, proximal end, rostrocaudal position, ventral view: starts below the joint surface for the lacrimal (0), starts below the joint surface for the postorbital (1).

Exemplars: LACM 28471 (0), MOR 1125 (1).

914. Frontal, joint surface for the prefrontal, proximal end, rostrocaudal distance from the orbital notch, ventral view: close together (0), widely separated by a long flange (1).

Exemplars: LACM 28471 (0), MOR 1131 (1).

915. Frontal, joint surface for the mesethmoid, form, ventral view: indistinct (0), coarse ventrally-flaring ridge (1), distinct peg-in-socket joint surface (2). **ORDERED**

Exemplars: LACM 28471 (0), DDM 344.1 (1), LACM 23845 (2).

Note: This is in reference to the joint surface for the mesethmoid that extends along the ventromedial surface of the cranial crest; ergo, it does not refer to the dorsal joint surface that attaches to the ventral surface of the frontal astride the midline.

916. Frontal, postorbital buttress, extent, dorsal view: does not reach caudally to the midlength of the dorsotemporal fossa (0), reaches the midlength of the fossa (1), extends caudal to the midlength of the fossa (2). **ORDERED**

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1), MOR 1131 (2).

917. Frontal, postorbital buttress, joint surface for the postorbital, form, lateral view: dorsoventrally shallow series of grooves (0); dorsoventrally shallow joint surface, dorsal ridge and ventral groove (1); dorsoventrally deep, concave and coarse (2). **ORDERED**
Exemplars: LACM 28471 (0), DDM 344.1 (1), MOR 555 (2).

918. Frontal, postorbital buttress, development, dorsal view: reduced, where it is not distinct from the rest of the bone (0); developed, where it is a distinct, dorsally-bulging structure (1).
Exemplars: LACM 28471 (0), MOR 1125 (1).

919. Frontal, postorbital buttress, differentiation, lateral view: dorsal ridge and ventral flange are continuous with each other (0); ridge and flange are separated from each other by a deep, slot-like groove, where the dorsal ridge is a caudolaterally facing disc-shaped joint surface and the flange is a rugose, laterally facing triangular and coarse joint surface (1).
Exemplars: DDM 344.1 (0), MOR 2822 (1).

920. Frontal, postorbital buttress, relative size of subordinate parts, lateral view: flange is larger than ridge (0), same size (1), ridge is larger than flange (2). **ORDERED**
Exemplars: DDM 344.1 (0), MOR 980 (1), MOR 1131 (2).

921. Frontal, postorbital buttress, flange, ventral margin, form and rostrocaudal orientation, lateral view: ventrally convex and horizontal (0), straight and extends rostroventrally (1).
Exemplars: DDM 344.1 (0), MOR 2822 (1).

922. Frontal, caudal shelf, suture, form, dorsal view: does not interdigitate (0), deeply interdigitating (1).
Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

923. Frontal, caudal shelf, mediolateral orientation, lateral view: extends lateroventrally at a low but distinct angle (more lateral than ventral) (0); extends slightly ventrolaterally, nearly laterally (1).
Exemplars: MOR 1131 (0), MOR 2822 (1).

924. Frontal, caudal shelf, joint surface, caudal margin, depth, dorsal view: shallowly inset (0), deeply inset (1).
Exemplars: MOR 1131 (0), MOR 1125 (1).

925. Frontal, caudal shelf, caudal fork, cleft, depth, dorsal view: shallow groove between tines (0), deep cleft between tines (1).
Exemplars: MOR 1131 (0), MOR 1125 (1).

926. Frontal, sagittal foramen, rostrocaudal position, dorsal view: rostral, at the level of the postorbital buttress (0); caudal, at the level of the postorbital shelf or the caudolateral corner of the bone (1).

Exemplars: DDM 344.1 (0), MOR 1125 (1).

Note: The *sagittal foramen* is the opening on the midline, on the interfrontal suture, which extends caudoventrally between the bones. The frontals are apposed to each other behind the foramen, forming the sagittal crest, and separate around the opening as ridges that extend rostrally.

927. Frontal, sagittal foramen, position relative to the dorsotemporal fossa, dorsal view: at or a short distance caudal to the rostral margin of the fossa (0), rostral to the fossa (1), far caudal to the rostral margin of the fossa (2). **ORDERED**

Exemplars: DDM 344.1 (0), CMNH 7541 (1), MOR 2822 (2).

Note: Given that this character might track the rostral margin of the fossa, it is included here to test that possibility.

Result: Character 927 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

928. Frontal, sagittal crest, mediolateral width, dorsal view: narrow (0), wide (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

929. Frontal, sagittal crest, rostral extent, dorsal view: does not reach the rostral margin of the dorsotemporal fenestra (0), reaches the rostral margin of the fossa (1).

Exemplars: DDM 344.1 (0), CMNH 7541 (1).

Note: This is a qualitative version of the quantitative character #87 that uses osteological landmarks.

930. Frontal, sagittal crest, embayment by the sagittal foramen, dorsal view: not embayed (0); embayed, where the medial surface of the crest curves laterally around the foramen (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

931. Frontal, orbit ceiling, medial region at the cranial crest, orientation, lateral and ventral views: vertical (0), medioventral (1), horizontal (2). **ORDERED**

Exemplars: LACM 28471 (0), DDM 344.1 (1), MOR 555 (2).

932. Frontal, dorsotemporal fossa, depth, lateral view (Carr, 1999): shallow, where the rostral and caudal ends are at the same horizontal level (0); deep, where the caudal end of the fossa is lower than the rostral end of the fossa (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

Ontogeny: Character first described in Carr (1999); transition from shallow to deep.

933. Frontal, dorsotemporal fossa, region of greatest depth, dorsal and lateral views: region of postorbital buttress (0), midregion of the postorbital shelf (1), rostral end of the shelf (2), caudal end of the shelf (3). **ORDERED**

Exemplars: LACM 28471 (0), CMNH 7541 (1), MOR 1125 (2), AMNH FARB 5027 (3).

934. Frontal, bone, depth, lateral or medial view: shallow (0), deep (1).

Exemplars: LACM 28471 (0), AMNH FARB 5029 (1).

Note 1: This character can be quantified by obtaining the ratio of the maximum depth of the interfrontal joint surface to the total length of the bone (dorsally exposed surface). In LACM 28471 (9.9 mm, 90.2 mm) the ratio is 11%, which corresponds to the *shallow* condition; in MOR 2822 (85.7 mm, 186.3 mm) the ratio is 46%, which corresponds to the *deep* condition.

Note 2: The correlate of a deep frontal that is in articulation with the skull roof (i.e., the interfrontal joint surface is concealed) is a dorsotemporal fossa that is deeply excavated and, hence, a distinct dorsoventral height difference between the deepest part of the fossa and the forehead is seen.

935. Frontal, dorsotemporal fossa, rostral margin, presence, dorsal view (Currie, 2003): undetectable (0), traceable or distinct (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

936. Frontal, dorsotemporal fossa, rostral margin, presence of a ridge or crest, dorsal view: absent (0), present (1).

Exemplars: LACM 28471 (0), AMNH FARB 5029 (1).

937. Frontal, dorsotemporal fossa, rostral extent, dorsal view: extends rostrally to the level of the caudal margin of the orbital notch (0), extends to the level of the proximal end of the prefrontolacrimal process (1), extends rostral to proximal end of the process (2). **ORDERED**

Exemplars: LACM 28471 (0), AMNH FARB 5029 (1), MOR 980 (2).

938. Frontal, dorsotemporal fossa, rostral region, form, dorsal view: concave fossa (0), convex surface (1).

Exemplars: LACM 28471 (0), DDM 344.1 (1).

939. Frontal, dorsotemporal fossa, region between sagittal crest and the contact for the postorbital shelf, form, dorsal view: convex (0), concave (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

940. Frontal, transition from the dorsotemporal fossa to the forehead, lateral view: level (0), dorsotemporal fossa extends rostradorsally at a low angle relative to the level forehead where they are set at a subtle angle to one another (1), fossa extends rostradorsally at a relatively steep angle relative to the level forehead where they are set at a distinct angle to one another (2).

ORDERED

Exemplars: LACM 28471 (0), CMNH 7541 (1), AMNH FARB 5117 (2).

Note: The *forehead* is the subcutaneous surface-covered region ahead of the dorsotemporal fossa.

941. Frontal, subcutaneous surface, entry into the sagittal foramen, dorsal view: enters (0); does not enter; i.e., the surface ahead of the foramen is covered by the dorsotemporal fossa (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

942. Frontal, forehead, rostrocaudal orientation, lateral view: horizontal (0), steep rostroventral angle (1), low rostroventral angle (2). **ORDERED**

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1), AMNH FARB 5027 (2).

943. Frontal, joint surface for the lacrimal, mediolateral width, dorsal view (Carr, 1999): narrow (0), wide (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

Ontogeny: Character first described in Carr (1999); transition from long and narrow to short and wide.

944. Frontal, joint surface for the prefrontal, width, dorsal view (Carr, 1999): narrow, longer than wide (0); wide, wider than long (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Ontogeny: Character first described in Carr (1999); transition from narrow to wide.

945. Frontal, groove across the dorsum of the prefrontolacrimal and prefrontonasal processes, along the prefrontal, depth, dorsal view: shallow (0), deep (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

946. Frontal, interfrontal suture, dorsal view: open (0), closed (1).

Exemplars: LACM 28471 (0), RSM 2523.8 (1).

947. Frontal, prefrontolacrimal process, form, dorsal view: stout emargination (0), narrow and triangular spike (1); stout, wide, and rostromedially hooked (2). **ORDERED**

Exemplars: LACM 28471 (0), LACM 23845 (1), LACM 150167 (2).

948. Frontal, joint surface for the prefrontal, position relative to the joint surface for the lacrimal, lateral view: a slot that incises the lateral edge of the bone that extends caudoventrally below the joint surface for the lacrimal (0), a socket that is positioned medial to the joint surface for the lacrimal and no longer extends below it except ventrolaterally (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

949. Frontal, joint surface for the prefrontal, form, lateral and rostral views: a shallow groove that incises the lateral surface of the bone below the joint surface for the lacrimal (0); a rostrally facing socket that is not roofed dorsally by bone; i.e., the joint surface is open dorsally and its caudal all only slightly tilts rostrorodorsally (more dorsal than rostral) (1); a deep, caudally extending socket that is concealed by an extensive roof of bone (2). **ORDERED**

Exemplars: LACM 28471 (0), LACM 23845 (1), LACM 150167 (2).

950. Frontal, sagittal crest(s), dorsal edge, texture, dorsal view: smooth (0), coarse (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

951. Frontal, nasal process, lateral edge from the rostral tip of the nasal ramus to the prefrontolacrimal process, orientation, dorsal view: extends more caudally than laterally (0), extends more laterally than caudally (1).

Exemplars: LACM 28471 (0), LACM 150167 (1).

952. Frontal, nasal ramus, form, dorsal view: long and wide (0), long and narrow (1), wide and truncated (2).

Exemplars: LACM 28471 (0), LACM 23845 (1), LACM 150167 (2).

953. Frontal, region between the joint surfaces for the prefrontals, form, ventral view: wide and flat with no distinction between airway and joint surface for the mesethmoid and bounded laterally by a narrow ridge that extends along the joint surface for the prefrontal and the region ahead of the cerebral fossa is concave; also the nonprefrontal joint surface of the bone occupies the entire surface between the prefrontolacrimal processes (0). The region is a relatively wide and deep platform with some distinction between the joint surface for the mesethmoid and the airway, and the shallowly concave medial part of the airway from the deeply excavated lateral part of the airway; also, the rostral end of the nonprefrontal joint surface of the bone occupies over half the width of the space between the prefrontolacrimal processes (1). The region is a relatively narrow and ventrally deep ridge with a sharp distinction between the ridge-like joint surface for the mesethmoid and steeply dorsolaterally extending airway that has little distinction between medial and lateral parts; also, the rostral end of the nonprefrontal joint surface of the bone occupies less than half the width of the space between the prefrontolacrimal processes (2).

ORDERED

Exemplars: LACM 28471 (0), LACM 23845 (1), LACM 150167 (2).

954. Frontal, parietofrontal suture, lateral extent, orientation, dorsal view: extends from caudomedially to rostromedially (0), extends mediolaterally to caudolaterally (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

955. Frontal, joint surface for the parietal, exposure, dorsal view: marginally exposed along the caudomedial edge of the bone (0), widely exposed and covers the caudomedial corner of the bone (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

956. Frontal, dorsotemporal fossa, mediolateral ridge ahead of the parietofrontal contact, presence, dorsal view: absent (0), present (1).

Exemplars: LACM 28471 (1), MOR 2822 (1).

957. Frontal, dorsotemporal fossa, ridge that extends across the rostromedial corner of the fossa, presence, dorsal view: absent (0), present (1).

Exemplars: LACM 28471 (0), MOR 008 (1).

958. Frontal, joint surface for the lacrimal, ridge that extends parallel to the edge of the joint surface, presence, dorsal view: absent (0), present (1).

Exemplars: LACM 28471 (0), MOR 008 (1).

959. Frontal, joint surface for the lacrimal, rostral edge, dorsally-extending flange, presence, dorsal view: absent (0), present (1).

Exemplars: LACM 28471 (0), MOR 980 (1).

960. Frontal, frontoparietal suture, medial extent, scar, presence, dorsal view: absent (0), present and leaves a divot or a raised scar on the frontal and a divot on the parietal (1).

Exemplars: LACM 28471 (0), MOR 008 (1).

961. Frontal, width increase, ventral view: narrow (0); wide, where the entire bone is extended laterally from the cranial crest lateralward (1).

Exemplars: DDM 344.1 (0), MOR 2822 (1).

PARIETAL (22 characters)

962. Parietal, depth of the bone, lateral view: shallow (0), deep (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

Note: This is a qualitative character given that the parietal is often in articulation with the skull roof. In the *shallow* condition, the bone is dorsoventrally shallow, wide, and nearly flat with a low sagittal crest, whereas in the *deep* condition the bone has a tall triangular mediolateral cross section and a distinct sagittal crest.

963. Parietal, sagittal crest, caudal end, extent, dorsal and caudal views: blends with the nuchal crest (0), extends dorsal to the nuchal crest (1).

Exemplars: LACM 28471 (0), CMNH 7541 (1).

964. Parietal, sagittal crest, width, dorsal view (Carr, 1999): narrow (0), wide (1).

Exemplars: LACM 28471 (0), AMNH FARB 5117 (1).

Ontogeny: The adult state of this character was first described in Carr (1999) for *T. rex*.

965. Parietal, sagittal crest, caudal end, height, dorsal and lateral views: tall ridge (0), low ridge (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

966. Parietal, sagittal crest, caudal end, creases, presence dorsal and lateral views: crest is defined by creases (0); creases are absent, producing a tent-like form (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

967. Parietal, sagittal crest, lowest point, position relative to interorbital region, lateral view (Carr, 1999): above the interorbital region (0), at same level or below the interorbital region (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from low to deep (*A. libratus*).

968. Parietal, nuchal crest, texture, dorsal view (Carr, 1999): smooth (0), rugose lateral to midline (1), rugosity reaches midline (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5027 (2).

Ontogeny: Character first described in Carr (1999); transition from smooth dorsum to a rugose dorsum.

969. Parietal, rostral margin, contact with frontal, form, dorsal view: parietal abuts frontal (0), parietal overlaps frontal (1).

Exemplars: LACM 28471 (0), FMNH PR2081 (1).

970. Parietal, nuchal crest, caudal surface above supraoccipital, pits, presence, caudal view: flat (0), penetrated by a shallow pair of insertion pits (1), deep pits (2). **ORDERED**
Exemplars: LACM 28471 (0), MOR 1131 (1), AMNH FARB 5027 (2).

971. Parietal, frontoparietal junction, dorsal view at sagittal crest, width, dorsal view: crest is narrow at the frontoparietal junction (0), the junction is wider than the crest rostral and caudal to it (1).
Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

972. Parietal, rostromedial process, exposure, dorsal view: widely exposed to view (0), marginally exposed (1), concealed by caudally impinging frontal (2). **ORDERED**
Exemplars: CMNH 7541 (0), MOR 1131 (1), AMNH FARB 5027 (2).

973. Parietal, parietosupraoccipital junction, pillar, presence, caudal view: low midline ridge (0), prominent midline ridge (1), parietal is elaborated into a ridge above each of the dorsal tines of the dorsal process of the supraoccipital (2). **ORDERED**
Exemplars: LACM 28471 (0), CMNH 7541 (1), AMNH FARB 5027 (2).

974. Parietal, nuchal crest, midline strut above supraoccipital, dorsal extent, distinctiveness: low (0), prominent (1).
Exemplars: LACM 28471 (0), MOR 1125 (1).

975. Parietal, nuchal crest, dorsal margin, midline indentation, dorsoventral depth of concavity, caudal view: shallow (0), deep (1).
Exemplars: LACM 28471 (0), CMNH 7541 (1).

976. Parietal, nuchal crest, dorsal edge, rostrocaudal length, dorsal view (Carr, 1999): short (0), long (1).
Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).
Ontogeny: The adult state of this character was first described in Carr (1999) for *T. rex*.

977. Parietal, nuchal crest, caudodorsal margin, distinct rim across entire crest, caudal view: indistinct, effectively absent (0); distinct rim (1).
Exemplars: CMNH 7541 (0), LACM 23845 (1).

978. Parietal, nuchal crest, caudal surface, concavity, dorsal extent, caudal view: approaches dorsal margin of crest (0), fades far below dorsal margin (1).
Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).
Note: The *concavity* refers to the pit that is situated between the midline of the nuchal crest and the lateral tine of the supraoccipital.

979. Parietal, nuchal crest, lateral edge, texture, lateral view: smooth (0), rugose (1).
Exemplars: CMNH 7541 (0), MOR 555 (1).

980. Parietal, nuchal crest, dorsal rugosities, extent, dorsal and rostral views: coarse along rostromedial edge of the crest (0), rugosities extend onto rostral surface of the crest (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

981. Parietal, nuchal crest, dorsolateral surface, form, dorsal view: convex (0), concave (1).

Exemplars: CMNH 7541 (0), LACM 23845 (1).

Note: The *dorsolateral surface* refers to the lateral half of the dorsum of the nuchal crest.

982. Parietal, nuchal crest, nuchal ridge, form, dorsal view: low, spur absent (0); prominent, caudally directed triangular spur (1).

Exemplars: LACM 28471 (0), MOR 1125 (1).

Note: The *nuchal ridge* is the vertical ridge on the midline that extends down the caudal surface to the nuchal crest to the dorsum of the supraoccipital.

983. Parietal, rostralateral process, base, ventrolaterally extending ridge, presence, caudolateral view: absent (0); present but subtle (1); present and distinct, extends ventrolaterally from the dorsal margin of the base of the process and fades out before reaching the laterosphenoid (2). **ORDERED**

Exemplars: CMNH 7541 (0), UWBM 99000 (1), FMNH PR2081 (2).

984. Parietal, rostral process, endocranial surface, midline divot, presence, ventral view: present (0), absent (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

Note: The divot occurs on the rostral surface of the mediolateral ridge that separates the cerebral region of the endocranial surface from the region caudal to it.

985. Parietal, rostral process, region ahead of the mediolateral ridge, form, ventral view: flares anterodorsally on either side of the midline, distinctly saddle-shaped surface (0); surface is effectively flat and only very subtly saddle-shaped, minimally flaring anterodorsally (1).

Exemplars: LACM 28471 (0), LACM 23845 (1).

Note: This flattening is consistent with the shallowing out of the cerebral fossae; this character is included to test that hypothesis of simultaneity.

Result: Character 985 was not optimized unambiguously on the ontogram; the hypothesis is unresolved.

ENDOCRANIUM (8 characters)

986. Endocranium, optic lobes, visibility in endocast, lateral view (Witmer and Ridgely, 2009): visible (0), not visible (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

987. Endocranium, flocculus, size, lateral view (Witmer and Ridgely, 2009): large (0), small (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

988. Endocranium, lateral canal of inner ear, lateral extension, dorsal view (Witmer et Ridgely, 2009): does not extend a great distance laterally (0), extends a great distance laterally (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

989. Endocranium, prohypophyseal sinus, presence, lateral view (Witmer and Ridgely, 2009): present (0), absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

990. Endocranium, ascending diverticulum of the rostral tympanic recess, presence, lateral view (Witmer and Ridgely, 2009): present (0), absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

991. Endocranium, caudal tympanic recess, communication with the lateral subcondylar recess, presence (Witmer and Ridgely, 2009): present (0), absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

992. Endocranium, cultriform process, extent of pneumatization, lateral view (Witmer and Ridgely, 2009): extensive (0), limited to the base (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

993. Endocranium, lateral subcondylar recess, invasive extent (Witmer and Ridgely, 2009): extends into the tuberal crest (0), barely extends into the tuberal crest (1)

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

LATEROSPHEOID (8 characters)

994. Laterosphenoid, orbital surface, form, rostral view: shallowly concave to subtly convex (0), deeply concave (1).

Exemplars: MOR 1125 (0), MOR 1131 (1).

995. Laterosphenoid, CN IV and rostral margin of bone, groove, rostral view: foramen lies within a distinct groove that extends along the rostral margin of the bone (0), groove is absent (1).

Exemplars: MOR 1125 (0), MOR 1131 (1).

996. Laterosphenoid, proximal region of the postorbital process, bulk, ventral view: massive and rostrocaudally long (0), delicate and rostrocaudally narrow (1).

Exemplars: MOR 1125 (0), MOR 1131 (1).

997. Laterosphenoid, foramen in the joint surface for the epipterygoid, position, lateral view: far medial from the lateral edge of the joint surface (0), close to the lateral edge of the joint surface (1).

Exemplars: MOR 1125 (0), MOR 1131 (1).

998. Laterosphenoid, orientation of the foramen for CN V₁, rostral view: rostrolateral (0), rostral (1).

Exemplars: MOR 1125 (0), RSM 2523.8 (1).

999. Laterosphenoid, caudal process, mediolateral ridge at dorsal margin, presence, dorsal and lateral views: present (0), absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

1000. Laterosphenoidoprotic suture, ridge along suture, presence, dorsal and lateral views: ridge is absent (0), ridge is present (1).

Exemplars: MOR 1125 (0), AMNH FARB 5117 (1).

1001. Laterosphenoidoparietal suture, form along peak of laterosphenoid, lateral view: bones form a low ridge long their line of apposition (0), bones are flat across the suture (1), suture lies within a concavity (2).

Exemplars: CMNH 7541 (0), MOR 1125 (1), MOR 1131 (2).

1002. Laterosphenoid, dorsum of body, form, dorsal view: shallowly concave (effectively absent) such that the laterosphenoid and parietal form a continuous surface (0); shallow such that the laterosphenoid is slightly inset relative to the parietal (1); deeply concave such that the laterosphenoid is deeply inset relative to the rostral process of the parietal (2). **ORDERED**

Exemplars: MOR 1125 (0), MOR 980 (1), MOR 008 (2).

OTOCCIPITAL (32 characters)

1003. Otoccipital, subcondylar fossa, presence, caudal view: distinct (0), shallow (1), obliterated by inflation (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5117 (2).

1004. Otoccipital, junction of the metotic strut and the paroccipital process, angle, caudal view: separated by a distinct angle (0), confluent, separated by only a gentle obtuse angle (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1005. Otoccipital, paroccipital process, width of the dorsal margin, dorsal view: narrow (0), wide, especially in region of the dorsal foramen (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

1006. Otoccipital, paroccipital process, distal end, orientation, distal view: vertical (0), dorsal half extends abruptly rostrad (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

1007. Otoccipital, neck of the occipital condyle, junction of neck with vertical occipital surface, pit, presence, dorsal and caudal views: dorsum of the neck is convex and a pit is absent (0), shallow pit is present (1), a deep pit penetrates the junction of the neck and vertical part of the otoccipital (2). **ORDERED**

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1), AMNH FARB 5027 (2).

1008. Otoccipital, paroccipital process, orientation, ventral margin, caudal view: extends laterally (0), extends dorsolaterally proximally and ventrolaterally distally (1).

Exemplars: CMNH 7541 (0), MOR 980 (1).

1009. Otoccipital, paroccipital process, distal end, rostral surface, texture, lateral view: joint surface for the squamosal is relatively smooth (0), entire surface is coarsened by numerous prominent ridges and grooves (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1010. Otoccipital, paroccipital process, joint surface for the squamosal, caudoventral margin, supporting ridge, presence, lateral view: absent (0), present (1).

Exemplars: LACM 23845 (0), RSM 2523.8 (1).

1011. Otoccipital, paroccipital process, distal end, large concavity positioned toward the dorsal edge of the process, dorsal bounding ridge, form, lateral view: ridge is a sharp-edged ledge above the concavity (0), ridge is rounded and laterally convex (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1012. Otoccipital, paroccipital process, ventral margin, groove, width ventral view: wide (as wide as a thumb) groove between ridges along leading and trailing edges of the process (0), narrow (less than a thumb width) groove between ridges (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

Note: The bifurcation is caudal (=distal) along the ventral surface of the process, immediately medial to the process's ventrolateral corner.

1013. Otoccipital, paroccipital process, distal end, caudal surface above the depressor mandibulae process, large foramen above the process, presence, caudal view: present (0), absent (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1014. Otoccipital, metotic strut, ventral tip, participation in the oval scar complex, caudal view: not scoured by the muscle complex (0), scoured by the oval scar complex (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

1015. Otoccipital, ridge that extends ventrolaterally from the neck of occipital condyle to the ventral margin of the paroccipital process, prominence, caudal view: low and subtle (0), distinct (1).

Exemplars: MOR 1125 (0), MOR 980 (1).

1016. Otoccipital, surface immediately above ridge that extends ventrolaterally from the neck of occipital condyle to the ventral margin of the paroccipital process, form, caudal view: concave fossa (0), inflated and convex such that the ridge forms the inset ventral margin of a bulge (1).

Exemplars: MOR 980 (0), MOR 008 (1).

SUBCONDYLAR RECESSES (1 character)

1017. Subcondylar recesses, distance between the subcondylar recesses within the subcondylar fossa, caudal view (Witmer and Ridgely, 2009): close together (0), far apart (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

BASIOCCIPITAL (22 characters)

1018. Basioccipital, occipital condyle, shape, caudal view (Carr, 1999): flattened and triangular (0), transversely (=mediolaterally) wide (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Note: The *wide* condition is equivalent to ‘reniform’.

Ontogeny: Character first described in Carr (1999); transition from flat and triangular to spherical and round.

1019. Basioccipital, occipital condyle, angle at which the condyle extends from the vertical plate, lateral view: low caudodorsal angle (0), right angle or caudoventral (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

1020. Basioccipital, occipital condyle, form, viewed caudoventrally and upside down: not glaniform, where the lateral rim is indistinct or absent (0); glaniform, rounded with ventrally flaring lateral perimeter (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1021. Basioccipital, occipital condyle, caudoventral surface, form, caudoventral and ventral views: flattened (0), distinctly convex (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1022. Basioccipital, occipital condyle, caudal margin, form, dorsal view: convex (0), concave (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1023. Basioccipital, occipital condyle, dimple, distinctiveness, caudal view: indistinct (0), distinct (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

1024. Basioccipital, ascending scars, prominence, caudal view (Bakker et al., 1988; Witmer and Ridgely, 2009): prominent (0), low (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

1025. Basioccipital, basal tuber, texture, caudal and ventrolateral views (Carr, 1999): smooth (0), irregular (1), coarse (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5117 (2).

Ontogeny: Character first described in Carr (1999); transition from smooth to coarse.

1026. Basioccipital, basal tubera, size relative to the basipterygoid processes, all views: same size (0), smaller than the basipterygoid processes (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

1027. Basioccipital, ventral margin medial to basal tuber, ventrally-extending flange, presence, caudal and ventral views: absent (0), present (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1028. Basioccipital, basituberal web, lateral extent, contribution to basal tuber, caudal view: not co-opted into basal tuber (0), co-opted into basal tuber (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1029. Basioccipital, ventral surface between tubera, form, ventral view (Carr, 1999): narrow but not blade-like, or long and convex (0); blade-like, with thickening at the midline (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Ontogeny: Character first described in Carr (1999); transition from flat to blade-like.

1030. Basioccipital, occipital condyle, neck, caudoventral view: excavated by a deep depression (0); small midline pit, pillars absent (1); deep pit between pillars (2); midline strut (3).

ORDERED

Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5117 (2), AMNH FARB 5027 (3).

1031. Basioccipital, ventral lappet, presence, caudal view: present and extends onto caudoventral surface of basituberal web (0), marginal or absent (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Note: The *lappet* is an extension of the smooth basisphenoid recess surface that extends caudoventrally around the ventral margin of the basituberal web, extending a short distance onto its caudoventral surface, where it overlaps the coarse surface of the bone.

1032. Basioccipital, portion within the basisphenoid recess, form, ventral view: midline strut (0), flat (1), strongly convex (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1131 (1), MOR 2822 (2).

1033. Basioccipital, vagus foramen, position, caudal view (Witmer and Ridgely, 2009): lateral (0), medial (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

1034. Basioccipital, ventral plate, vertical ridge, dorsal component, presence, caudal view: a ridge is completely absent from this region (0), a low or prominent ridge is present here (1).

Exemplars: CMNH 7541 (0), MOR 980 (1).

Note: The *vertical ridge* is equivalent to the “midline scar” of Bakker et al. (1988).

1035. Basioccipital, ventral plate, vertical ridge, ventral component, presence, caudal view: absent (0), present as a pair of prominent parallel ridges that culminate ventrally in stout caudolaterally extending spurs (1), parallel ridges are low (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), MOR 1131 (2).

1036. Basioccipital, basituberal web, ventral margin, form, ventral view: evenly convex across the midline such that the entire margin curves rostrally (0), curves caudally (concave) in the region of the midline (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Note: The osteological term *basituberal web* (Bakker et al., 1988) is used here as it has chronological priority over the “intertuberal lamina” of Witmer and Ridgely (2009).

1037. Basioccipital, basituberal web, ventral surface, foramina, presence, ventral view: absent (0), present (1).

Exemplars: CMNH 7541 (0), MOR 1131 (1).

1038. Basioccipital, subcondylar foramen, shape, caudolateral view: triangular (0), teardrop (1), oval (2). **ORDERED**

Exemplars: MOR 1125 (0), MOR 980 (1), RSM 2523.8 (2).

1039. Basioccipital, subcondylar foramen, emits a deeply inset channel ventrolaterally from its lower margin, presence, caudal view: absent where the foramen opens onto the flat surface of the fossa (0), present (1).

Exemplars: MOR 1125 (0), MOR 1131 (1).

BASISPHEOID (14 characters)

1040. Basisphenoid, basiptyergoid process, caudolateral scar for muscle attachment, presence, lateral and caudolateral views: absent (0); present as coarse collar, triangular spur, or massive knob (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1041. Basisphenoid, basiptyergoid process, caudal edge, form, lateral and caudal views: flange absent (0), flange present that extends caudally from the process (1).

Exemplars: CMNH 7541 (0), MOR 980 (1).

1042. Oval scar, orientation, ventral view (Carr, 1999): caudoventral (0), medioventral (1), lateroventral (2). **ORDERED**

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1), AMNH FARB 5117 (2).

Ontogeny: Character first described in Carr (1999); transition from lateroventral to variable.

1043. Oval scar, texture, caudal and ventral views (Carr, 1999): smooth (0), irregular (1), coarse (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), MOR 555 (2).

Ontogeny: Character first described in Carr (1999); transition from smooth to coarse.

1044. Basisphenoid, oval scar, medial edge, form, ventral view: a low ridge (0), prominent and bounds the basisphenoid recess laterally (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1045. Basisphenoid, oval scar, size, caudoventral view (Carr, 1999): small (0), large (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

Ontogeny: Variant of character first described in Carr (1999); transition from narrow to wide.

1046. Basisphenoid, lateral flange of the oval scar, extent, lateral and caudal views: indistinct (0), distinct and coarse flange that extends from the metotic strut to the dorsal half of the oval scar (1).

Exemplars: CMNH 7541 (0), MOR 555 (1).

1047. Basisphenoid, cultriform process, subsellar recess, size, ventral view (Witmer and Ridgely, 2009): small (0), large (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

1048. Basisphenoid, cultriform process, spout, presence, ventral view: absent (0), present (1).

Exemplars: MOR 1125 (0), MOR 980 (1).

Note: The *spout* refers to the condition where the caudoventral end of the subsellar recess extends ventrally as a spout-like rim relative to the rest of the basisphenoid lateral to it.

1049. Basisphenoid, basiptyergoid web, ventral margin, form, caudoventral view: horizontal (0), dorsally concave (1), ventrally convex in the midline region (2). **ORDERED**

Exemplars: CMNH 7541 (0), MOR 1125 (1), MOR 980 (2).

1050. Basiptyergoid web, ventral surface, length, ventral view: rostrocaudally short and bladelike (0), rostrocaudally lengthened (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

1051. Basisphenoid, lateral margin between oval scar and basiptyergoid process, form, caudal view: not embayed (0), deeply embayed (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1052. Basisphenoid, flange that extends from the ventral edge of the preotic pendant to the junction between the ventral margin of the basisphenoid and the basiptyergoid process, lateral view: present (0); absent, where it is modified into a low ridge (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

1053. Basisphenoid, tab rostralateral to basal tuber, extent on lateral surface, lateral view: marginal with indistinct rostral margin, a plane change in the caudoventral corner of the bone (0); sharply defined rostral margin (1).

Exemplars: MOR 1125 (0), MOR 555 (1).

SUPRAOCCIPITAL (3 characters)

1054. Supraoccipital, dorsal process, width relative to foramen magnum, caudal view: approximately the same width (0), wider than the foramen magnum (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

1055. Supraoccipital, bar that extends horizontally across the supraoccipital between the dorsal process and the beak-like process, form, caudoventral view: low, such that the caudal surface of the bone is concave in horizontal section and the ventral surface of the bar is not prominent or flattened such that the region of the beak-like process is indistinct, the entire surface is broadly convex in vertical section (0); prominent bar, such that it crosses the midregion of the body of the bone and the caudoventral surface of the bar is flattened, which enhances the convex region of the beak-like process (1).

Exemplars: CMNH 7541 (0), MOR 980 (1).

1056. Supraoccipital, body, ventral process, beak-like extension into the foramen magnum, presence and size, caudal view: does not extend into the foramen magnum (0), hypertrophied into a low beak-like process (1), prominent beak-like process (2). **ORDERED**
Exemplars: CMNH 7541 (0), MOR 1125 (1), AMNH FARB 5027 (2).

BRAINCASE SUTURES (6 characters)

1057. Laterosphenoidoparietal suture, closure, lateral view: open (0), closed (1).
Exemplars: AMNH FARB 5117 (0), MOR 1125 (1).

1058. Laterosphenoidoprootic suture, closure, lateral view: closed (0), partly closed (1), open (2). **ORDERED**
Exemplars: MOR 1125 (0), MOR 980 (1), MOR 1131 (2).

1059. Laterosphenoidorbitosphenoid suture, closure, rostral view: open (0), closed (1).
Exemplars: AMNH FARB 5117 (0), MOR 1125 (1).

1060. Parietootoccipital suture, closure, caudal view: open (0), closed (1).
Exemplars: MOR 1125 (0), RSM 2523.8 (1).

1061. Otoccipital, otoccipitobasioccipital suture, subcondylar region (not occipital condyle) closure, caudal view: open (0), closed proximally (1).
Exemplars: CMNH 7541 (0), MOR 1125 (1).

1062. Otoccipital, otoccipitobasioccipital suture, occipital condyle, closure, caudal view: open (0), closed (1).
Exemplars: CMNH 7541 (0), AMNH FARB 5117 (1).

DENTARY (63 characters)

1063. Dentary, depth of bone, lateral view: shallow (0), intermediate (1), deep (2).
ORDERED
Exemplars: LACM 28471 (0), CMNH 7541 (1), CM 9380 (2).

1064. Dentary, ratio of the maximum depth of the front end of the bone to the maximum depth of the caudal end of the bone: 0.67 to 0.73 (0), 0.82 (1).
Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1).

1065. Dentary, bone, width, ventral view: uniform width in dentigerous region, but becomes narrow rostrally and caudally (0); dentigerous region approximately doubles or doubles in width in the rostralmost region (1).
Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1066. Dentary, bone, width, rostral view: narrow, where lateral surface is flat and the bone is widest ventrally (0); wide, where the lateral margin is convex, and the widest part is at or below midheight (1).
Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1067. Dentary, bone, lateral surface, form, ventral view: gently sinuous (0); straight (1); convex rostrally, concave caudally (2). **ORDERED**

Exemplars: AMNH 5050 (0), BMRP 2002.4.1 (1), CM 9380 (2).

1068. Dentary, bone, alveolar margin, ventrally deepest point of curvature below a straight line drawn between the convex rostral margin and the intermandibular process, lateral view: alveolus 10 to 11 (0), alveolus 9 (1), alveolus 8 (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

1069. Dentary, bone, shallowest point caudal to the chin relative to the alveoli, lateral view: alveolus 9 (0), alveolus 10 to 11 (1), alveolus 7 to 8 (2). **ORDERED**

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: The *chin* refers to the abrupt change in direction between the ventral margin of the bone and the rostr dorsally extending rostral end of the bone, as seen in lateral and medial views.

1070. Dentary, bone, ratio of shallowest point caudal to chin and convex dorsal margin to the length of the tooth row: 21% (0), 28% or greater (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1071. Dentary, extent of the convex margin of the tooth row (until the tooth row curves dorsally), lateral view: alveolus 7 (0), alveolus 8 or greater (1).

Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).

1072. Dentary, lateral surface, width, dorsal view: widest next to caudal part of tooth row (0), widest caudally and intermediately wide rostrally (1), widest at rostral and caudal ends of the tooth row (2). **ORDERED**

Exemplars: AMNH FARB 5050 (0), MOR 1125 (1), CM 9380 (2).

1073. Dentary, caudal plate, ventral surface, orientation, ventral view: limited to medial edge of bone (0), extends to ventrolateral edge (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1074. Dentary, rostral margin of chin below enlarged rostral foramen, lateral view: evenly convex with rest of margin (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1075. Dentary, enlarged rostral foramen, orientation, lateral view: faces more laterally than rostrally (0), faces more rostrally than laterally (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1076. Dentary, last foramen of the dorsal row, dorsoventral height of sulcus, lateral view: dorsoventrally shallow (0), dorsoventrally deep (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1077. Dentary, last foramen of the dorsal row, position relative to the last alveolus, lateral view: beside alveolus (0), caudal to alveolus (1).

Exemplars: AMNH FARB 5050 (0), BMRP 2002.4.1 (1).

1078. Dentary, last foramen of the ventral row, position relative to the last alveolus, lateral and medial views: below last alveolus (0), ahead of last alveolus (1).

Exemplars: AMNH FARB 5050 (0), BMRP 2002.4.1 (1).

1079. Dentary, proximity of the ventralmost foramen of the dorsal row above the ventral margin of the bone, lateral view: 40% or greater of the depth of the bone (0), less than 40% (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: This is measured by dividing the distance of the foramen from the dorsal margin of the bone by the total height of the bone through the level of the foramen.

1080. Dentary, symphysis, caudal extent relative to the alveoli, medial view: alveoli four to five (0), alveolus three or less (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

1081. Dentary, ventral margin, region of the chin, lateral view: extends rostroventrally toward the chin, and is concave before it reaches the chin (0); extends rostroventrally to the chin without deviating (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1082. Dentary, texture of the subcutaneous region of the chin, lateral view: lightly textured (0), highly rugose (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1083. Dentary, interdental plates, spacing, medial view: adjacent plates do not touch each other (0), two touch each other (1), more than two touch or are close together (2). **ORDERED**

Exemplars: AMNH FARB 5050 (0), BMRP 2002.4.1 (1), CM 9380 (2).

1084. Dentary, interdental plates of the midregion, rostral margin, notch, presence, medial view: absent (0), shallow notches present (1), deep notches (2). **ORDERED**

Exemplars: AMNH FARB 5050 (0), BMRP 2002.4.1 (1), MOR 1125 (2).

1085. Dentary, interdental plates, height, medial view: as tall as, or almost as tall as, the laterodorsal margin of the bone (0); lower than the laterodorsal margin of the bone (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1086. Dentary, first alveolus, presence, dorsal view: present and open (0), shallow dimple or absent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: Credit for this character belongs to J. R. Horner, who first drew it to the author's attention in 2007.

1087. Dentary, first three alveoli, relative size, dorsal view: alveoli increase in size from mesial to distal (0), second and third alveoli are over twice the size of the first and are nearly equal in length with each other (1).

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1).

1088. Dentary, alveolus at which the sockets decrease in length, dorsal view: alveolus six to seven (0), alveolus four to five (1).

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1).

1089. Dentary, last alveolus, caudal margin, orientation, medial view: low caudodorsal (more caudal than dorsal) angle (0), steep (more dorsal than caudal) angle (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1090. Dentary, zone of rostromedially extending interdental septa, dorsal view: first seven septa (0), greater than seven septa (1), less than seven septa (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1), NHMUK R7994 (2).

1091. Dentary, lingual bar, dorsoventral depth of joint surface for intercoronoid on dorsal edge of the free end of the bar, medial view: less than a quarter the depth of the free end (0), a quarter the depth of the free end (1), joint surface displaced dorsally by a tall ridge that extends along the dorsomedial edge of the proximal end of the free end of the bar (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), MOR 555 (2).

1092. Dentary, lingual bar, dorsal view, width, dorsal view: narrow along its entire length (0); widened medially, except along the last three alveoli (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1093. Dentary, lingual bar, coarse patch, presence, medial view: absent (0), distinct coarse patch below alveoli three to six (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1094. Dentary, lingual bar, depth rostradorsal to the joint surface for the splenial, medial view: constant depth (0); is dorsoventrally shallow, producing a waist in the bar (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1095. Dentary, lingual bar, joint surface for the splenial, distinctiveness, medial view: indistinct (0), elevated (1), inset (2). **ORDERED**

Exemplars: AMNH FARB 5050 (0), MOR 1125 (1), NHMUK R7994 (2).

1096. Dentary, lingual bar, depth below the last alveoli relative to shallowest point, medial view: deepens only moderately, shallower than rostral end (0); deepens by a third to a half (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1097. Dentary, lingual bar, caudal end, dorsoventral depth, medial view: deep, where the bar increases in dorsoventral height toward its rostral end gradually (0); shallow, where the bar increases abruptly, where the bar is extremely dorsoventrally shallow proximally between the intercoronoid and Meckelian groove (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1098. Dentary, lingual bar, notch at rostral end of the joint surface for the intercoronoid, depth or height, medial view: dorsoventrally shallow notch (0), dorsoventrally deep notch (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: This is equivalent to the “anterior step of the lingual bar” and “margin” of Dalman and Lucas, 2015, 2017) that is claimed “does not seem to change during ontogeny” (Dalman and Lucas, 2015). The opposite view is taken here, where the ontogenetic transition from shallow to deep is seen.

1099. Dentary, lingual bar, joint surface for the intercoronoid, form, dorsal view: narrow and indistinct along top of lingual bar (0), distinct and caudal to midregion it is a wide and medioventrally sloping joint surface and rostrally it is wide and coarse (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1100. Dentary, Meckelian groove, dorsoventral position, medial view: below midheight rostrally, at midheight caudally (0); below midheight rostrally, above midheight caudally (1); at midheight rostrally, above midheight caudally (2). **ORDERED**

Exemplars: AMNH FARB 5050 (0), BMRP 2002.4.1 (1), NHMUK R7994 (2).

1101. Dentary, Meckelian groove, proximal end of the ventral margin, ridge, presence, medial view: not delimited by a distinct ridge (0), delimited by a distinct ridge (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1102. Dentary, Meckelian groove, ventral margin, rostral extent, presence, medial view: ventral margin of the groove fades out and disappears ahead of the joint surface for the rostral process of the splenial (0), extends ahead of the joint surface and closely approaches the Meckelian foramen (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1103. Dentary, Meckelian groove, proximal end, dorsal margin, medial view: bounded by a sharp, ventrally-extending and blade-like ridge (0); overhanging condition is absent (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1104. Dentary, Meckelian foramen, position relative to alveoli, medial view: alveolus five (0), equal to or less than alveolus four (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1105. Dentary, rugosity, position relative to the primary Meckelian foramen, medial view: rostradorsal (0), caudodorsal (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1106. Dentary, stout vertical ridge that bounds Meckelian foramen rostrally, presence, medial view: absent (0); present with a distinct, rugose ventral end (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1107. Dentary, rostral end of Meckelian groove rostradorsal to (i.e., ahead of) the Meckelian foramen, depth into bone, medial view: shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1108. Dentary, ventral bar, joint surface for the splenial, rostromedial edge, caudomedial view: groove (0), socket that opens medially (1), socket that opens caudally (2).

Exemplars: AMNH FARB 5050 (0), MOR 1125 (1), CM 9380 (2).

1109. Dentary, ventral bar, proximal end, depth, medial view: shallow in that it is not significantly deeper than the distal (rostral) end of the bar (0), deep in that is approximately a third deeper than the distal end of the bar (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1110. Dentary, ventral bar, depth relative to the lingual bar, medial view: less than or marginally deeper than lingual bar rostrally (0), significantly deeper than lingual bar caudally (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1111. Dentary, ventral bar, depth below the Meckelian fossa, medial view: shallow (0), deep (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1112. Dentary, ventral bar, region below the Meckelian fossa, dorsoventral height, medial view: rostral end is shallow ridge that tapers gradually from a subtle inflection point (0), rostral end dorsoventrally tall such that abruptly decreases in dorsoventral height at a distinct inflection point (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1113. Dentary, caudal plate, medial surface along caudoventrally extending part of ventral bar, elevated joint surface, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1114. Dentary, ventral bar, joint surface for the splenial ahead of the Meckelian fossa, texture, medial view (Carr, 1999): nearly smooth or a coarse facet (0), reinforced by rostroventrally trending grooves and ridges (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus* and *D. torosus*.

1115. Dentary, separation of the lingual and ventral bars, position, medial view: below alveolus 14 (0), below alveolus 10 to 11 (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1116. Dentary, caudal plate, Meckelian fossa, rostral margin, position, medial view: the margin within the joint surface for the splenial extends ventrolaterally to blend with the medial surface of the bone; i.e., a deep groove that received the splenial separates the margin of the fossa from the dorsal surface of the ventral bar (0); the margin extends ventromedially to blend with the dorsomedial edge of the ventral bar (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1117. Dentary, Meckelian fossa, rostral end, number of pits lateral to the ridge that extends ventromedially or ventrolaterally (see preceding character), number, caudomedial view: single large pit medial to the ridge (0); a second small pit ventrolateral to the ridge, formed by the pit-like rostroventral end of the joint surface for the splenial, the original large pit is dorsal to the subordinate pit (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

Note: Variation of a character that was described in Dalman and Lucas (2015, 2017).

1118. Dentary, caudal plate, Meckelian fossa, rostral margin, position relative to teeth, medial view: below the fourth last dentary tooth (0), between the third and fourth last dentary teeth (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1119. Dentary, caudal plate, Meckelian fossa, mediolateral cross section, shape, caudal view: triangular, with a wide apex and a narrow base (0); rectangular where the fossa is bounded ventrally by a shelf that extends ventromedially (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1120. Dentary, tooth root bulges in the rostradorsal corner of the Meckelian fossa, exposure, medial view: exposed marginally in the fossa in medial view, above the level of the Meckelian groove (0); expanded and bulge into the fossa, below the level of the groove (1).

Exemplars: AMNH FARB 5050 (0), CM 9380 (1).

1121. Dentary, caudal plate, lateral surface rostral to the dorsal process of the external mandibular fenestra, rostrally-extending ridge from margin, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1122. Dentary, caudal plate, secondary intermandibular process, presence, lateral view: absent (0), a low ridge (1), present (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

1123. Dentary, caudal plate, caudal margin, form, lateral view: straight or shallowly concave (0), deeply concave (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1124. Dentary, caudal plate, region of the external mandibular fenestra and ventral external mandibular fenestra process, prominent horizontal ridges extend rostrally from this region, presence and prominence, medial view: present, but low (0); prominent (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

1125. Dentary, caudal plate, ridges dorsal and caudodorsal to the ventral bar in the region of the joint surface for the caudal process of the splenial, medial view: absent or indistinct (0), prominent (1).

Exemplars: AMNH FARB 5050 (0), MOR 1125 (1).

1126. Dentary, caudal plate, caudodorsolateral margin, form, caudolateral view: a narrow bladelike edge (0); a caudally convex, mediolaterally wide, and coarse joint surface for the surangular (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

SPLENIAL (6 characters)

1127. Splenial, rostradorsal margin, notch, presence, medial and lateral views (Hurum and Sabbath, 2003): notch for the lingual bar is absent (0), present (1).

Exemplars: MOR 1125 (0), AMNH FARB 5027 (1).

1128. Splenial, rostral mylohyoid foramen, recess along rostradorsal margin, presence, medial view: vanishingly indistinct (0), present (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

1129. Splenial, rostral mylohyoid foramen, orientation of long axis, medial view: more caudal than dorsal (0), more dorsal than caudal (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

1130. Splenial, joint surface for the dentary beneath the rostral mylohyoid foramen, form, lateral view: flat (0), reinforced by a wide longitudinal ridge such that it is convex (1), ridge is broken into a peg-in-socket contact (2). **ORDERED**

Exemplars: LACM 23845 (0), MOR 1125 (1), FMNH PR2081 (2).

1131. Splenial, rostral process, extent relative to alveoli, medial view: extends rostrally to the level of alveolus 10 (0), extends to alveolus 8 (1), alveolus 7 (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), CM 9380 (2).

1132. Splenial, caudal process, caudal tip, ridge, medial view: distinct horizontal ridge extends rostrally from the caudal tip of the bone (0), ridge is absent (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

SURANGULAR (33 characters)

1133. Surangular, bone, depth, lateral view (Carr, 1999): shallow (0), deep (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Ontogeny: Character first described in Carr (1999); transition from shallow to deep.

1134. Surangular, retroarticular process, medial flange, dorsoventral position, caudal view: at midheight of process (0), below midheight (1), above midheight (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), AMNH FARB 5027 (2).

1135. Surangular, retroarticular process, ventral margin, medial view: continuous between process and body of the bone (0), separated by a cleft that extends from caudolaterally to rostromedially (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: The cleft is produced by the joint surface for the prearticular, which extends onto the lateral surface of the bone in specimens where the cleft is present.

1136. Surangular, rostral glenoid process, width, dorsal view: narrow crest that does not extend medially to the coronoid process (0), wide and extends to the coronoid process (1).
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1137. Surangular, rostral glenoid process, rostral surface, dorsal view: penetrated by a very small foramen (0), penetrated by a large and deep foramen or pit (1), or a large concavity (2).
ORDERED
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

1138. Surangular, rostral glenoid process, orientation, lateral view: rostradorsal (0), dorsal (1).
Exemplars: MOR 1125 (0), BMRP 2002.4.1 (1).

1139. Surangular, glenoid fossa, form, lateral view: long and shallow (0), short and deep (1).
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1140. Surangular, caudal glenoid process, height, lateral view: almost as tall as or taller than the rostral process (0), significantly shorter than the rostral process (1).
Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1).

1141. Surangular, caudal glenoid process, apical tip, lateral view: split is absent, a coherent process (0); split by a deep sulcus that extends from the joint surface for the articular (1).
Exemplars: CMNH 7541 (0), BMRP 2002.4.1 (1).
Note: In the *split* condition, the groove separates out a small, dorsally extending, tooth-like process from the lateral surface of the caudal glenoid process. This is not to be confused with the dorsolateral, fan-like process that abuts the caudal glenoid process from behind.

1142. Surangular, caudal glenoid process, form of medial joint surface, medial view: deeply concave (0), flat (1).
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1143. Surangular, retroarticular process, cleft behind caudal glenoid process, length and depth, medial view: dorsoventrally short and shallowly incised (0), long and deep (1).
Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1144. Surangular, lateral scar, texture and dorsoventral depth, lateral view (Carr, 1999): smooth and shallow (0); rugose and shallow, penetrated by a pit (1); rugose and deep, penetrated by a pit (2). **ORDERED**
Exemplars: LACM 28471 (0), BMRP 2002.4.1 (1), MOR 1125 (2).
Ontogeny: Character first described in Carr (1999); transition from shallow and smooth to deep and rugose.

1145. Surangular, region below the lateral scar, muscle fossa, presence, lateral view: present with a deeply inset dorsal margin that includes the caudal end of the joint surface for the angular in its boundaries (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1146. Surangular, coronoid region, dorsoventral height, lateral view (Carr, 1999): shallow such that the surangular shelf closely approaches the dorsal margin of the bone (0), deep such that the shelf does not closely approach the dorsal margin of the bone (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Ontogeny: Character first described in Carr (1999); transition from low to tall (*A. libratus*).

1147. Surangular, coronoid process, caudal extent, lateral and dorsal views: diminishes before reaching the glenoid region (0); deep and extends caudally to the glenoid region, merging with the rostral glenoid process (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1148. Surangular, coronoid process, demarcation of dorsal edge, medial view: fades rostrally (0), distinct rostrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1149. Surangular, caudal surangular foramen, rostrocaudal position, lateral view: close to glenoid (0), far rostral to glenoid (1).

Exemplars: BMRP 2002.4.1(0), MOR 1125 (1).

1150. Surangular, surangular shelf, rostral extent, lateral view: begins to diminish a short distance rostral to the caudal surangular foramen (0), extends rostrally for a great distance ahead of the caudal surangular foramen before fading (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

Note: Rostral extent is in reference to the margin of the external mandibular fenestra (emf). In the *short distance* condition, the shelf stops short of the emf, above the joint surface for the angular; in the *great distance* condition, the shelf reaches the margin of the emf, fading at the rostral end of the joint surface for the angular.

1151. Surangular, surangular shelf, mediolateral width, ventrolateral view: narrow, lateral edge of shelf extends a short distance (1.5 cm) lateral to the caudal surangular foramen (0); extends a great distance (3-4 cm) lateral to the caudal surangular foramen (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1152. Surangular, surangular shelf, width, lateral view: caudal end fades below glenoid region (0), caudal end is wide and differentiated below glenoid region (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1153. Surangular, surangular shelf, lateral edge rostradorsal to the caudal surangular foramen, dorsal view: abruptly concave (0), subtly concave or extends rostrally uninterrupted (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1154. Surangular, medial process, orientation, medial view: extends rostrally such that it extends over the caudal margin of the caudal surangular foramen (0), widely separated from the caudal surangular foramen and extends caudomedially away from it (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1155. Surangular, medial process, rostral extent, medial view: extends only a short distance rostroventrally beyond the caudal margin of the caudal surangular foramen (0), extends rostrally below the caudal surangular foramen, almost reaching or reaching its rostral margin (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1156. Surangular, ridge that extends rostroventrally from the medial process, form, medial view: narrow and flat (0); a wide, mediadorsally extending ridge (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1157. Surangular, joint surface for the angular, orientation, lateral view: uniformly convex and extends ventromedially to the ventral edge of the bone (0), ventral quarter extends abruptly ventrolaterally as a shelf (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1158. Surangular, ventral margin below rostral end of the caudal surangular foramen, notch, presence, lateral and medial views: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

1159. Surangular, ventral margin between notch and external mandibular fenestra, form, ventral view: thin and blade-like (0), wide coarse convex surface to peg-in-socket (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1160. Surangular, lateral mandibular process, rostral margin, form, lateral view: shallowly concave (0), deep notch (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1161. Surangular, joint surface for the dentary on the intermandibular process, lateral view: fades before reaching the split between intramandibular process and lateral mandibular process (0), deep and reaches the caudal end of the split between the processes (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1162. Surangular, intermandibular process, medial joint surface for the dentary, ventral margin, medial view: supported ventrally by a flange such that it does not reach the ventral margin of the process (0), flange is absent and it reaches the ventral margin (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1163. Surangular, intermandibular process, medial joint surface for the dentary, depth, medial view: deeply concave (0); shallowly concave, almost flat (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1164. Surangular, intermandibular process, orientation, dorsal view: process extends rostrally and is straight (0), extends rostrolaterally (1), distal half of the process curves rostromedially (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), MOR 1125 (2).

ANGULAR (4 characters)

1165. Angular, external mandibular fenestra, margin, texture, dorsolateral view (Carr, 1999): smooth (0), coarse (1).

Exemplars: CMNH 7541 (0), MOR 1125 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus*, *D. torosus*, and *T. rex*.

1166. Angular, caudal process, caudoventral fossa delimited by a distinct rostroventrally-extending ridge, presence, lateral view: absent (0), subtle (1), present and distinct (2).

ORDERED

Exemplars: CMNH 7541 (0), UWBM 99000 (1), MOR 008 (2).

1167. Angular, primary ridge that extends rostr dorsally from the ventral margin of the caudal process onto the rostral process, dorsoventral position, medial view: does not closely approach the dorsal margin of the proximal end of the rostral process (0), closely approaches dorsal margin (1).

Exemplars: LACM 23845 (0), AMNH FARB 5029 (1).

1168. Angular, secondary ridge above the primary ridge that extends rostr dorsally from the ventral margin of the caudal process, form, medial view: indistinct (0), distinct (1).

Exemplars: LACM 23845 (0), AMNH FARB 5029 (1).

PREARTICULAR (6 characters)

1169. Prearticular, caudal ramus, depth, medial and lateral views (Carr, 1999): shallow (0), deep (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Ontogeny: This character was first described in Carr (1999); transition from shallow to deep.

1170. Prearticular, dorsal margin, position, medial and lateral views (Carr, 1999): caudal such that the dorsal and ventral margins are parallel with each other (0), rostral such that the dorsal and ventral margins converge rostrally toward each other (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5029 (1).

Ontogeny: This character was first described in Carr (1999); transition from caudal to rostral.

1171. Prearticular, angulation between the caudal and rostral rami, lateral and medial views: gradual obtuse curve (0), abrupt angulation (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

1172. Prearticular, shaft rostral to the angular flange, width, dorsal view: narrow, where the lateral surface is not visible lateral to the dorsal surface, and it tapers as it extends rostrally (0); lateral surface visible lateral to dorsal surface and is parallel-sided as it extends rostrally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1173. Prearticular, rostral process, form, medial and lateral views (Carr, 1999): strap-like (0), paddle-like (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

Ontogeny: First observed in Carr (1999).

1174. Prearticular, prearticuloangular buttress, presence, ventral view: absent (0), present (1).

Exemplars: CMNH 7541 (0), FMNH PR2081 (1).

DENTITION (11 characters)

1175. Premaxillary arcade, proximity of teeth to each other, external view: premaxillary teeth are closely spaced, where they are almost in contact with each other (0), teeth are widely separated from each other by gaps (1).

Exemplars: CMNH 7541 (0), AMNH FARB 5027 (1).

1176. First maxillary tooth crown (Carr, 1999): incisiform, where the tooth matches that of the premaxillary teeth, except apically it is labiolingually flattened, but, like the premaxillary teeth, it is much smaller than the succeeding maxillary teeth (0); subincisiform, where the crown most closely resembles the succeeding maxillary teeth in form and large size, aside from the mesiolingually positioned mesial carina and gently convex, distolingually facing lingual surface (1).

Exemplars: LACM 28471 (0), CM 9380 (1).

Ontogeny: This character was first described in Carr (1999) for *A. libratus* and *D. torosus*.

1177. First maxillary tooth, proportions of labiolingual width to mesiodistal length: width is greater than length, the ratio is greater than 1.0 (0); length is greater than width, the ratio is less than one (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

1178. First maxillary tooth, labial ridge, presence, labial view: present (0), absent (1).

Exemplars: DDM 1561.14 (0), BMRP 2002.4.1 (1).

Note: In the juvenile condition, a distinct labial ridge extends apicobasally from the apex, fading at crown midheight. The mesial edge of the ridge is indistinct, whereas the distal edge of the ridge is distinct and the external surface of the crown next to the distal edge is subtly inset, enhancing its appearance.

1179. First maxillary tooth, lingual ridge, form, lingual view: sharply defined ridge (0), distinct but convex in horizontal cross section (1); absent, the lingual surface is evenly convex (2). **ORDERED**

Exemplars: DDM 1561.14 (0), BMRP 2002.4.1 (1), UWBM 99000 (2).

1180. Maxillary teeth, position of the mesiodistally longest tooth of the series: tooth six (0), less than tooth six (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

1181. First dentary tooth, size relative to the second dentary tooth: small, half the length of the second tooth, 49% to 51% the size of the second tooth (0); large, greater than half the size to the second dentary tooth, greater than or equal to 63% (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (tooth) (1).

1182. First dentary tooth, form, all views (Larson, 2008): subconical (0), subincisiform (1).

Exemplars: LACM 28471 (0), AMNH FARB 5027 (1).

Note: In a *subincisiform* tooth, the labial surface is strongly convex, the lingual surface is convex, and it becomes increasing strutlike (narrow) toward the base of the crown, whereas toward the apex the strut diminishes in size and the labial surface is broadly flattened on either side of it, producing the incisor-like form. The distal surface of the strut is flatter than the strongly convex mesial half of the lingual surface, such that the strut appears to be tilted slightly mesially. The long axis of the crown is distolingual to mesiolabial, the axis that connects the carinae extends from distolabial to mesiolingual, the distal carina appears to extend further basally than does the mesial carina, in mesial view the crown is sinuous and curves slightly labially from its upper half, as is seen in the premaxillary teeth.

1183. Second dentary tooth, mesiodistal length relative to that of the third dentary tooth (var. Larson, 2008): small, 64% or less the length of the third tooth (0); large, at least 75% the length of the third tooth (1).

Exemplars: BMRP 2002.4.1 (0), RSM 2523.8 (1).

Note: Variant of Larson (2008), who used the lengths of the alveoli instead of erupted teeth since specimens often lack erupted teeth. The actual lengths of the first two teeth are used here, where available, to test the ratios obtained from alveoli. The notion of congruence between tooth length and alveolus length is tested here: in the subadult BMRP 2002.4.1 the ratio of the length of the second alveolus (11 mm) to the third alveolus (18.3 mm) is 60%. This result is comparable for the ratio obtained from the teeth, where the ratio of the length of the second tooth (9.7 mm) to the third tooth (15.1 mm) is 64%.

1184. Second dentary tooth, form, all views (cf. Larson, 2008): transitional between incisiform and blade-like morphotypes, labiolingually narrow, ‘twisted’ axially with a prominent mesiolingual heel (0); incrassate blade-like crown, with a mesiodistally oriented long axis (1); incrassate crown, with a distolingual to mesiolabial long axis that displaces the carinae onto the sides of the crown (2). **ORDERED**

Exemplars: LACM 28371 (0), BMRP 2002.4.1 (1), CM 9380 (2).

Note: This character is based on the so-called “dentary incisor count” of Larson (2008) that he defines in terms of size, where the first two teeth are closer in length to each other than to the greatly enlarged third tooth, or, alternatively, the second and third teeth are close in size to each other (see the preceding character). The view is taken here that the tooth morphology does change based on position along the mesial end of the tooth row and ontogenetically from juveniles to adults. Therefore, the qualitative version of this character is included here.

1185. Dentary teeth, mesiodistally longest tooth of the series: tooth 8 (0), tooth 4 (1).

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1).

CERVICAL SERIES (1 character)

1186. Inclinations of the faces of the centra, lateral view: steeply inclined, resulting in a series that is not strongly sinuous (0); low inclination, resulting in a series that is distinctly sinuous (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

ATLAS INTERCENTUM (22 characters)

1187. Atlas, dorsal margin, form, anterior view: ventrally concave, U-shaped (0); ventrally concave, V-shaped (1).

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1).

1188. Atlas, ventral nonjoint surface, exposure below the posterior joint surface, posterior view: widely exposed below and beyond the ventral and ventrolateral surfaces of the posterior joint surface (0), narrowly exposed (1).

Exemplars: NHMUK R7994 (0), MOR 008 (1).

1189. Atlas, joint surface for the odontoid, orientation, posterior view: extends anteroventrally (0), faces primarily dorsally (1), faces posteroventrally (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), MOR 008 (2).

1190. Atlas, pedicle for neurapophysis, dorsal surface, exposure, anterior view: dorsal surface extends widely into view (0), dorsal surface is blocked from view (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1191. Atlas, joint surface for the neurapophysis, deepest part of joint surface, orientation, lateral view: faces anteriorly (0), faces anterodorsolaterally (1).

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1).

1192. Atlas, joint surface for the neurapophysis, ventral extension, lateral view: ventral extension is absent (0), ventral extension that extends ventrally onto the lateral surface of the bone as a narrow and flat facet that is situated closer to the posterior surface of the bone than to its anterior surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1193. Atlas, joint surface for the odontoid, form, dorsal view: deeply concave (0), gently concave (1), flat to gently convex (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), MOR 008 (2).

1194. Atlas, joint surface for the odontoid, midline ridges and divot, form, dorsal view: ridges and divot are present and distinct (0), divot is missing and the ridges are low (1), ridges are absent and the dorsum of the joint surface is featureless (2).

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), MOR 008 (2).

1195. Atlas, dorsum, anterolateral ridge and groove, form, dorsal view: present and distinct (0), present but low (1), absent (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), MOR 008 (2).

1196. Atlas, joint surface for the occipital condyle, anteroventral extension, presence, anterior and lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1197. Atlas, joint surface for the occipital condyle, ventral rim, dorsal extent, anterior view: extends dorsally to the joint surface for the neurapophysis (0), fades far ventral to the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1198. Atlas, joint surface for the axial intercentrum, posterodorsal ridge, presence and form, posterior view: absent (0), present but indistinct (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1199. Atlas, concavity below posterodorsal ridge of the joint surface for the axial intercentrum, form and presence: present but indistinct (0), absent (1).

Exemplars: NHMUK R7994 (0), MOR 008 (1).

1200. Atlas, plane change between the joint surface for the axial intercentrum with that for the odontoid, posterodorsal view: sharp (0), not sharp (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1201. Atlas, nonjoint ventral surface, exposure around the joint surface for the occipital condyle, anterior view: extends around the ventral and ventrolateral margins of the joint surface, and is extended as flanges at the ventrolateral corners (0); ventrolateral flanges are absent, narrowly exposed below ventral margin of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1202. Atlas, ventrolateral flange, form, lateral view: tapers as it extends anterodorsally (0), expanded and tapers posterodorsally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1203. Atlas, surface posterodorsal to dorsal end of ventrolateral flange, lateral view: smooth (0), coarse (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1204. Atlas, posteroventral nonjoint surface, exposure, posterior view: narrowly exposed to view (0), entirely blocked from view (1).

Exemplars: NHMUK R7994 (0), MOR 008 (1).

1205. Atlas, lateral surface, form, lateral view: concave fossa posterior to dorsal end of ventrolateral flanges (0), fossa reduced to a groove between the posterolaterally expanded flange and the joint surface for the axial intercentrum (1).

Exemplars: NHMUK R7994 (0), MOR 008 (1).

1206. Atlas, foramen of the lateral fossa, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1207. Atlas, ventral nonjoint surface, ridges texture, extent, ventral view: covers the entire ventral surface (0), limited to the anterior half of the ventral surface (1).

Exemplars: NHMUK R7994 (0), MOR 008 (1).

1208. Atlas, neurapophysis-intercentrum suture, closure, anterior and posterior views: open (0), closed (1).

Exemplars: BMRP 2002.4.1 (0), MOR 008 (1).

1209. Atlas, shape, anterior view: significantly wider than tall, with a height to width ratio of 58% (0); not significantly wider than tall, with a width to height ratio of 66% or greater (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23844 (1).

Note: The ratio of BMRP 2002.4.1 is based on the height of 36.8 mm (cast) mm and width of 63.5 mm (cast); the ratio of LACM 23844 is based on the height of 97.2 mm and width of 146.8 mm.

1210. Atlas, form, lateral, dorsal, and ventral views: anteroposteriorly short and plate-like (0), anteroposteriorly long and trending toward block-like (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23844 (1).

1211. Atlas, joint surface for the odontoid, exposure, anterior view: widely exposed in anterior view (0), blocked from view by the dorsally-expanded joint surface for the occipital condyle (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23844 (1).

1212. Atlas, notches produced by the joint surface for the neurapophysis, dorsal view: joint surface flattens the anterodorsolateral corner of the bone (0), joint surface produces a deep notch that separates the dorsum from the joint surface for the occipital condyle (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23844 (1).

1213. Atlas, ventral rim of the joint surface for the occipital condyle, form, anterior view: the ventral rim is a sharp ridge (0); the rim is an expanded, lip-like ridge (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23844 (1).

ATLAS NEURAPOPHYSIS (1 character)

1214. Atlas neurapophysis, dorsolateral process, form, all views: thin (0), robust (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

AXIS (61 characters)

1215. Axis, vertebral canal, shape, anterior view: mediolaterally wider than dorsoventrally tall (0), dorsoventrally taller than wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1216. Axis, vertebral canal, shape, posterior view: mediolaterally wider than dorsoventrally tall (0), dorsoventrally taller than wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1217. Axis, odontoid (=atlantal pleurocentrum), form, anterior view: glaniform with a ventrally convex ventral margin and convex anterodorsal surface (0), glaniform with a triangular notch (apex dorsally) in the ventral margin and a flattened anterodorsal surface separated into left and right halves by an indistinct vertical ridge (1), as in state 1 but a distinct bump separates the halves (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1), MOR 980 (2).

1218. Axis, odontoid, anterodorsal margin, form, dorsal and lateral views: anterior and dorsal surfaces join along a low mediolaterally extending rim (0), rim is tall and distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1219. Axis, axial intercentrum, anterior joint surface, form, anterior view: very gently concave mediolaterally, and gently convex to concave dorsoventrally, overall a flattened joint surface (0); prominent rim is present, but the joint surface is flat (1); gently concave and bounded ventrally by a prominent rim (2); deeply concave and bounded ventrally by a prominent rim (3).

ORDERED

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), MOR 2925 (2), FMNH PR2081 (3).

1220. Axis, axial intercentrum anterior joint surface, ventral margin, separation from the ventral intercentrum surface, anterior view: joint surface and ventral surface meet along a sharp edge, groove is absent (0); join along a blunt edge, groove is absent (1); a deep groove separates the ventral edge of the joint surface from the ventral surface of the intercentrum (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), MOR 2925 (1), FMNH PR2081 (2).

1221. Axis, axial intercentrum, dorsal margin, form, anterior view: entire margin is shallowly concave (0); bat-shaped - overall concave, but with a distinct dorsal process on the midline and on the lateral extremes of the dorsal margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1222. Axis, surface between the axial intercentrum joint surface and the odontoid, texture, anterior view: smooth (0); coarse and intrudes on the intercentrum only (1); extremely coarse and rugose, intrudes on the edges of the intercentrum joint surface and the odontoid (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), MOR 2925 (1), FMNH PR2081 (2).

1223. Axis, axial intercentrum joint surface, ratio of dorsoventral height to mediolateral width: dorsoventrally shallow (0), dorsoventrally deep (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1224. Axis, axial intercentrum, anteroventral margin, form, anterior and lateral views: sharp ridge (0), blunt convex ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1225. Axis, axial intercentrum, anteroventral margin, dorsoventral position, lateral view: a very short distance above the anteroventral edge of the axial pleurocentrum (0), distinctly positioned dorsal to the level of the anteroventral edge of the axial pleurocentrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1226. Axis, axial intercentrum, dorsoventral height relative to the axial pleurocentrum: dorsoventrally short, approximately one third the height of the axial pleurocentrum (0); dorsoventrally tall, approximately half the height of the axial pleurocentrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1227. Axis, axial intercentrum, shape, ventral view: anterior margin is gently convex, posterior margin is gently convex with a slight anterior concavity at its midwidth (0); anterior margin is convex, posterior margin is posteriorly convex (1); anterior margin is posteriorly concave, posterior margin is posteriorly convex (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), FMNH PR2081 (2).

1228. Axis, axial intercentrum, anterior margin, form, ventral view: ventral surface flares anteroventrally to the anteroventral edge of the bone, meets the anterior surface along a sharp ridge (0); ventral surface is bounded anteriorly by a prominent mediolaterally extending lip-like ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1229. Axis, axial intercentrum, lateral margin, anteroposterior length, ventral view: anteroposteriorly narrow and laterally convex (0), anteroposteriorly long and laterally anteroposteriorly (relatively) straight (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1230. Axis, axial intercentrum, concave ventral surface, lateral extent, lateral view: reaches the lateral margin of the bone (i.e., the parapophysis stops short of the axial intercentrum, and is limited to the axial pleurocentrum) (0); limited to the ventral and lateroventral surface of the bone, separated from the laterodorsal margin of the bone by a convex and laterally-facing surface of the ventral end of the parapophysis (i.e., the parapophysis extends ventrally onto the lateral surface of the axial intercentrum) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1231. Axis, parapophysis, form and texture, lateral view: convex and lightly coarse (0), deeply concave and extremely coarse (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1232. Axis, parapophysis, size relative to the centrum posterior to it, lateral view: parapophysis is a thick but anteroposteriorly narrow and vertically oriented ridge that does not extend posteriorly, since it is limited to the anterolateral edge of the axial pleurocentrum (0); massive and posteriorly impinging joint surface that reduces the anteroposterior length of the pleurocentrum in half (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1233. Axis, parapophysis, form, ventral view: a low convexity parallel to the anterolaterally extending lateral surface of the centrum (0); a prominent, posterolaterally pointing process (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1234. Axis, parapophysis, dorsal extent, lateral view: reaches the level of the dorsal margin of the odontoid (0), stops at the level of the dorsal third of the odontoid (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1235. Axis, attachment scar that extends around the posterior edge of the parapophysis, form, lateral view: a subtle excavation with a lightly coarse texture (0), a coarse and distinctly inset scar (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1236. Axis, attachment scar that extends around the posterior edge of the parapophysis, posterior end, position relative to the primary pneumatic foramen of the centrum, lateral view: scar extends toward the anteroventral margin of the foramen (0), scar extends toward the anterodorsal margin of the foramen (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1237. Axis, axial pleurocentrum, posterior joint surface, form, lateral view: sharply anteriorly concave where the dorsal and ventral halves of the joint surface extend anteriorly and join at the centrum midheight at an abrupt angle (0), angulation is absent (1).
Exemplars: BMR P2002.4.1 (0), FMNH PR2081 (1).

1238. Axis, axial pleurocentrum, posterodorsal edge, form, lateral view: abuts the pedicle at a sharp plane change, a dorsal flange is absent (0); extends dorsally beyond the external surface of the pedicle as a low, but distinct flange (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1239. Axis, primary pneumatic foramen, anteroposterior position, lateral view: positioned slightly closer to the posterior edge of the centrum than to the anterior edge (0); positioned adjacent to the posterior edge of the centrum, far posterior to the anterior edge of the centrum (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1240. Axis, primary pneumatic foramen, dorsoventral position, lateral view: level with the midheight of the odontoid (0), level with the suture between the ventral margin of the odontoid and the dorsal margin of the axial intercentrum (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1241. Axis, primary pneumatic fossa, anterodorsal margin between the transverse process and the parapophysis, form, lateral view: centrum is only undercut below the transverse process, the dorsal margin of the fossa is bounded by a low anteroventrally extending ridge that fades before it reaches the parapophysis (0); entire dorsal margin of the fossa is deeply excavated by the fossa, producing a prominent and sharp edged ridge that reaches the parapophysis (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1242. Axis, anterior joint capsule surface, texture, lateral and ventral views: lightly rugose, a narrow fringe of lineations around the anterior margin of the centrum that form a narrow path on the ventral midline that widens toward the posterior margin of the centrum, ventral surface is convex, a concavity is absent from the ventral midline (0). Relief of ridges is subdued, ridges are present, but not coarse (1). Coarsely textured fringe around the anterior margin of the centrum that abruptly increases in length ventrally, covering the anterior half of the centrum, and on the ventral midline produces a deep and coarse concavity below the ventral midlength of the centrum; the texture widens behind this to reach the posterior edge of the centrum (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), FMNH PR2081 (2).

1243. Axis, axial pleurocentrum, posterior joint capsule surface, form, lateral view: extends posterodorsally from the ventral surface where it is broadly exposed, and then is limited to the posterolateral edge of the centrum (0); extends anterodorsally from the ventral surface where it is widely exposed before extending posterodorsally around and behind the primary pneumatic fossa (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1244. Axis, axial pleurocentrum and posteroventral surface of the pedicle, texture, lateral view: the pedicle is lightly rugose and convex (0), pedicle and adjacent axial pleurocentrum are coarsely rugose and excavated (flat to gently concave) by the coarse surface of the posterior joint capsule (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1245. Axis, axial pleurocentrum, relative width, ventral view: wide such that the lateral surfaces extend at a low (more posterior than medial) posteromedial angle, where the primary pneumatic foramina are blocked from view (0); narrow such that the lateral surfaces are deeply and abruptly concave, where the lateral edges of the foramina are exposed to view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1246. Axis, axial pleurocentrum, anteroventral neurovascular foramina, presence and size, ventral view: small and indistinct (0); large, distinct, and positioned anteroventral to the primary lateral pneumatic fossa (1); foramina are absent (2).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1), MOR 2925 (2).

1247. Axis, axial pleurocentrum, ventral margin, form, lateral view: the ventral surface of the centrum is gently dorsally concave and extends along a low posteroventral angle to its posteroventral corner (i.e., the posteroventral region of the centrum does not extend significantly ventrally relative to the anteroventral region such that the anterior and posterior joint surfaces are not strongly offset) (0), a relatively deeply dorsally concave ventral surface that extends steeply posteroventrally to the posteroventral corner of the centrum (i.e., the posteroventral region extend significantly ventrally relative to the anteroventral region such that the anterior and posterior joint surfaces are distinctly offset) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1248. Axis, axis pleurocentrum, posterior joint surface, dorsoventral position of the deepest part of the concavity, posterior view: approximately at the midheight of the joint surface (0), above the midheight of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1249. Axis, axial pleurocentrum, hypapophysis, dorsoventral depth, posterior view: dorsoventrally shallow or absent (0), dorsoventrally deep such that it makes up nearly the ventral third of the posterior surface of the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1250. Axis, centrum complex, shape, lateral view: rectangular, long axis is oriented anteroposteriorly (0); wedge shaped, where the dorsal end is narrower than the ventral end (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1251. Axis, pedicle, lateral surface deep to the transverse process, lateral view: deeply concave (0), bulbously convex such that it contacts the medial surface of the transverse process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1252. Axis, transverse process, orientation, lateral view: curves steeply (more vertical than anterior) anteroventrally (0), curves steeply (more vertical than posterior) posteroventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1253. Axis, dorsoventral distance between the ventral end of the transverse process and the primary pneumatic foramen of the centrum, lateral view: the transverse process reaches or extends ventrally past the dorsal margin of the foramen (0); widely separate, where the ventral tip of the transverse process does not reach the foramen (1). **Exemplars:** BMRP 2002.4.1 (0), FMNH PR2081 (1).

1254. Axis, spinous process, anterior interspinous ligament scar, form, anterior view: distinct and mediolaterally narrow (0), indistinct and narrow (1), indistinct and mediolaterally wide (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), FMNH PR2081 (2).

1255. Axis, spinous process, posterior interspinous ligament scar, posteroventral view: anteroposteriorly long and narrow midline ridge that extends nearly the entire posterior height of the process (0); intermediate with a very low and indistinct dorsal ridge, but with a ventrally concentrated coarse scar that is not yet root-like or anteroposteriorly short and narrow midline ridge that extends dorsally from the postspinal fossa, limited to the ventral quarter of the process (1); root-like structure that extends directly posteriorly from the postspinal fossa, the posterior surface of the spinous process is otherwise smooth (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), NHMUK R7994 (1), FMNH PR2081 (2).

1256. Axis, spinous process, dorsolateral process, dorsoventral height, lateral view: dorsoventrally thin sheet (0), dorsoventrally massive process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1257. Axis, spinous process, spinopostzygapophyseal lamina that extends from the medial edge of the epiphysis to the dorsolateral process of the spinous process, orientation, posterior view: dorsolateral (0), dorsomedial (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1258 Axis, spinous process, posterior surface, form, posterior view: virtually flat and not continuous with the postspinal fossa (0), deeply anteriorly concave and essentially continuous with the postspinal fossa (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1259. Axis, spinous process, posterior surface, slot and lamina, form, posterior view: slot and lamina distinctly separates the posterior surface of the process from the postspinal fossa (0), indistinct and does not effectively separate the concave posterior surface of the process from the postspinal fossa (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1260. Axis, lamina, pneumatic recess, number of chambers, anterior view: a small opening with a flat ventral floor and without subordinate chambers in view (0), two or four subordinate chambers separated by prominent struts (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1261. Axis, lamina, contralateral pneumatic recesses, anterior extent, anterior view: contralateral recesses do not extend across the anterior surface of the lamina, they are widely separated structures (0); recesses join each other by extending across the anterior surface of the vertebral arch above the vertebral canal, removing the anteroventral part of the interspinous ligament scar (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1262. Axis, proximity of joint surface of the prezygapophysis and the odontoid, anterior view: close, separated only by a narrow gap (0); separated by a wide gap, where the prezygapophysis is elevated upon on a distinct stalk (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1263. Axis, prezygapophysis, nonjoint surface, thickness, anterior view: thin such that it is nearly completely blocked from view by the joint surface (0); thick, where it is not blocked from view and forms a stout ventrolateral process that extends past the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1264. Axis, prezygapophysis, pedicle below joint surface, anterior surface, form, anterior view: mediolaterally narrow strut and smooth (0), mediolaterally wide stalk excavated by a coarse muscle scar (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1265. Axis, joint surfaces of the contralateral prezygapophyses, proximity to each other, anterior view: widely separated (0), closely approach each other (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1266. Axis, stalk of the prezygapophysis, mediolateral width relative to the vertebral canal, anterior view: narrower than the vertebral canal (0), wider than the vertebral canal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1267. Axis, prespinal fossa, shape, anterior view: low triangle that is wider than tall (0), tall triangle that is at least as tall as it is wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1268. Axis, lamina, neurovascular foramen dorsal to the pneumatic recess, size, lateral view: minute and circular (0), large and elliptical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1269. Axis, joint surface of the prezygapophysis, orientation of long axis, lateral and dorsal views: posterodorsal (0), anterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1270. Axis, joint surface of the postzygapophysis, form, posteroventral view: nearly flat to gently convex (0), subtly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1271. Axis, angle between the anteromedially converging and uniting laminae between the postzygapophyses, posteroventral view: obtuse angle (0), acute angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1272. Axis, pedicle that forms the stalk of the postzygapophysis, orientation, posterior view: extends dorsomedially (0), extends dorsolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1273. Axis, joint surface of the postzygapophysis, shape, posteroventral view: rounded square that is slightly mediolaterally wider than anteroposteriorly long (i.e., does not reach the vertical pillar of the pedicle) (0), distinctly teardrop shaped (anteromedial point, posterolateral convexity) and mediolaterally wider than anteroposteriorly long (i.e., medially extended such that it reaches the vertical pillar of the pedicle) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1274. Axis, paired pits between the joint surfaces of the postzygapophyses and in the ceiling of the vertebral canal toward its posterior edge, form, posteroventral view: shallowly excavated teardrop shaped excavations (0), deep, funnel-like anterodorsomedially extending pits (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1275. Axis, neurocentral suture, closure: open (0), closed (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

POSTAXIAL CERVICALS (1 character)

1276. Postaxial cervicals, centra, form: distinctly opisthocoelous, and slightly procoelous (0); opisthocoelous, where the anterior joint surface is convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CERVICAL VERTEBRA 3 (10 characters)

1277. Cervical 3, spinous process, dorsal processes, differentiation, dorsal view: well differentiated (0), poorly differentiated (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1278. Cervical 3, spinous process, posterolateral processes, orientation, dorsal view: posterolateral (0), lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1279. Cervical 3, spinous process, dorsal processes, orientation, dorsal view: in a transverse row (0); not in a row, where the lateral processes are positioned ventrally relative to the midline process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1280. Cervical 3, spinous process, form, anterior and lateral views: short, anteroposteriorly flat, and extends at a low posterodorsal angle (0); tall, anteroposteriorly long, and extends vertically (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1281. Cervical 3, centrum, pneumatic foramen, form, lateral view (Brochu, 2003): single opening (0), bifid (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1282. Cervical 3, postzygapophysis, hyosphene, presence, posterior view: virtually absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1283. Cervical 3, diapophysis, associated foramina, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1284. Cervical 3, spinous process, anterior surface, pneumatic foramina, presence, anterodorsal view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1285. Cervical 3, diapophysis, joint surface, form: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1286. Cervical 3, intraprezygapophyseal lamina, form at the midline of the vertebral arch, anterior view: horizontally oriented (0), U-shaped (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CERVICAL VERTEBRA 5 (5 characters)

1287. Cervical 5, hypantra, presence, anterior and dorsal views: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1288. Cervical 5, hypapophysis, presence, ventral view: absent (0), present.

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1289. Cervical 5, joint surface of the prezygapophysis, anteromedial margin, form, dorsal view: angular (0); concave, producing a claw-shaped prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1290. Cervical 5, intraprezygapophyseal lamina, shape, anterior view: horizontally oriented (0), U-shaped (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1291. Cervical 5, centrum, ventral margin, anterior view: distinctly ventrally convex (0), straight (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CERVICAL VERTEBRA 6 (4 characters)

1292. Cervical 6, centrum, type, anterior and posterior views: amphicoelous, where a shallow groove crosses the anterior joint surface and the posterior joint surface is unambiguously concave (0); opisthocoelous, where the anterior joint surface is convex and the posterior joint surface is concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1293. Cervical 6, diapophysis, joint surface, form: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1294. Cervical 6, epiphyses, presence, lateral and dorsal views: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1295. Cervical 6, spinous process, shape, anterior and posterior views: tall and narrow (0), triangular (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CERVICAL VERTEBRA 8 (4 characters)

1296. Cervical 8, centrum, type, anterior and posterior views: amphicoelous (0), opisthocoelous (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1297. Cervical 8, transverse process, form, lateral, anterior, and posterior views: mediolaterally narrow and anteroposteriorly long (0), columnar (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1298. Cervical 8, diapophysis, joint surface, form: concave (0), convex (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1299. Cervical 8, spinous process, shape, anterior and posterior views: tall and narrow (0), triangular (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DORSAL SERIES (9 characters)

1300. Dorsal vertebrae, postzygapophysis, nonjoint surface, foramina, type, posterolateral view: small numerous foramina (0), large pneumatic foramina (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1301. Dorsal A (p14), centrum, anterior joint surface, form, anterior view: entire surface is concave (0), concavity is groove-like (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1302. Dorsal B (p15), centrum, anterior joint surface, form, anterior view: entire surface is concave (0), concavity is groove-like (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1303. Dorsal series, spinous process, mediolateral width, trend, anterior view: width increases toward the sacrum (0), width decreases toward the sacrum (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1304. Dorsal series, anterior dorsals, spinous process, posterior edge, position relative to the posterior edge of the centrum, lateral view: above the posterior edge of the centrum (0), short distance posterior to the centrum (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1305. Dorsal series, middle dorsals, spinous process, length relative to centrum, lateral view: half the centrum length (0), close to the same length as their corresponding centra (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1306. Dorsal series, middle dorsals, spinous process, height relative to centrum, lateral view: same height as centrum (0), 1.5 times the height of the centrum (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1307. Dorsal series, neurocentral suture closure, lateral view: all sutures are open (0), open from the eighth to last dorsal (1), open from the eleventh to last dorsal (2). **ORDERED**
Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1), FMNH PR2081 (2).

1308. Dorsal series, hypapophyses, presence, ventral view: absent (0), present (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DORSAL VERTEBRA A (=p15, sensu Brochu, 2003) (2 characters)

1309. Dorsal vertebra A (=p15), hypantrum, ratio of the dorsoventral height of the hypantrum to the mediolateral width of the prezygapophysis: the height of the hypantrum is less than the width prezygapophysis (0), the height of the hypantrum is greater than the width of the prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1310. Dorsal vertebra A (=p15), infrapostzygapophyseal fossa, perforation of bone, lateral view: does not perforate through the bone (0), perforates through the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DORSAL VERTEBRA B (=p16, sensu Brochu, 2003) (3 characters)

1311. Dorsal vertebra B (=p16), prezygapophysis, ratio of the height of the hypantrum to the width of the joint surface of the prezygapophysis, anterior view: less than the width of the joint surface of the prezygapophysis (0), greater than the width of the prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1312. Dorsal vertebra B (=p16), anterior centrodiapophyseal lamina, form, lateral view: prominent strut that forms the stalk of the prezygaophysis (0), slender and joins the transverse process posterior to the prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1313. Dorsal vertebra B (=p16), transverse process, dorsum, presence of pneumatic foramina, dorsal view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DORSAL VERTEBRA D (=p 20, 21; sensu Brochu, 2003) (6 characters)

1314. Dorsal vertebra D (=p 20, 21), centrum, type: amphicoelous (0), prosulcate and posteriorly convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1315. Dorsal vertebra D (=p 20, 21), prezygapophysis, joint surface, length to width ratio, dorsal view: as wide as long (0), wider than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1316. Dorsal vertebra D (=p 20, 21), prezygapophysis, joint surface, orientation, anterior view: primarily dorsomedially and laterally it curves ventrolaterally (0), dorsomedially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1317. Dorsal vertebra D (=p 20, 21), hypantrum, ratio of dorsoventral height to the mediolateral width of the joint surface of the prezygapophysis, anterior view: greater than half the width of the prezygapophyseal joint surface (0), less than a third of the width of the prezygapophyseal joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1318. Dorsal vertebra D (=p 20, 21), transverse process, dorsum form, dorsal view: distinctly convex (0), flat (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1319. Dorsal vertebra D (=p 20, 21), transverse process, orientation, anterior view: dorsolateral (0), lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DORSAL VERTEBRA E (=p 22, sensu Brochu, 2003) (4 characters)

1320. Dorsal vertebra E (=p 22), prezygapophysis, lateral fossa, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1321. Dorsal vertebra E (=p 22), intrapostzygapophyseal fossa, penetration of bone, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1322. Dorsal vertebra E (=p 22), transverse process, dorsum, form, dorsal view: convex (0), flat (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1323. Dorsal vertebra E (=p 22), spinous process, lower third, large foramen, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

SACRUM (1 character)

1324. Sacrum, spinous processes, extent relative to acetabulum, dorsal view: extends a great distance ahead of acetabulum, a short distance behind acetabulum (0); extend a short distance ahead of the acetabulum, a great distance posterior to the acetabulum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL SERIES (3 characters)

1325. Neurocentral sutures, closure, external view: completely closed sutures do not extend ahead of caudal 5 (0), completely closed sutures extend to base of tail (1).

Exemplars: BMRP 2002.4.1 (1) RSM 2523.8 (1).

1326. Transition point, location of loss of transverse processes along caudal series: reduced to a ridge at the 15th caudal (0), reduced to a ridge at the 18th caudal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1327. Transition point, location of prezygapophyseal processes that extend ahead of the prezygapophyseal joint surfaces along caudal series: 10th caudal (0), 13th caudal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 1 (12 characters)

1328. Caudal vertebra 1, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: centrum is as long as tall (0), centrum is distinctly taller than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1329. Caudal vertebra 1, centrum, large centrally positioned neurovascular foramen, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1330. Caudal vertebra 1, anterior interspinous ligament scar, anterior extent, lateral view: narrowly exposed in lateral view (0); widely exposed in lateral view, exceeds that of the posterior ligament scar (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1331. Caudal vertebra 1, spinous process, angulation between ventral and dorsal halves, distinctiveness, lateral view: indistinct (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1332. Caudal vertebra 1, spinous process, orientation, lateral view: extends slightly posterodorsally (0), vertical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1333. Caudal vertebra 1, spinous process, dorsal margin, lateral view: horizontally oriented and straight (0), widens distinctly and the dorsal edge is convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1334. Caudal vertebra 1, spinous process, smooth lateral surface, form, lateral view: anterior and posterior edges converge at the dorsal quarter of the process (0), margins diverge such that the interspinous ligament scars form the corners of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1335. Caudal vertebra 1, spinous process, sides, anterior and posterior views: parallel throughout their height (0), diverge dorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1336. Caudal vertebra 1, lateral surface between transverse process and prezygapophysis, foramina, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1337. Caudal vertebra 1, ridge that extends anteriorly from the transverse process to the prezygapophysis, orientation, lateral view: extends along the midheight of the prezygapophysis (0), extends anteroventrally to the ventral margin of the prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1338. Caudal vertebra 1, postspinal fossa, ventral end, mediolateral width, posterior view: wide (0), narrow (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1339. Caudal vertebra 1, postzygapophysis, ventral lamina, orientation, posterior view: horizontal (0), dorsolateral at a low angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 2 (3 characters)

1340. Caudal vertebra 2, prezygapophysis, joint surface, orientation, anterior view: steeply ventromedially to dorsolaterally, faces more medially than dorsally (0); equally medially and dorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1341. Caudal vertebra 2, hypantrum, orientation, anterior view: steeply dorsomedially to ventrolaterally (0), equally ventral and lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1342. Caudal vertebra 2, prezygapophysis, width and orientation relative to the dorsal series, anterior view: mediolaterally narrow and vertical (0), wide and not vertical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 3 (13 characters)

1343. Caudal vertebra 3, centrum, large centrally positioned neurovascular foramen, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1344. Caudal vertebra 3, centrum, ventral margin, form, lateral view: shallowly dorsally concave (0), deeply and distinctly dorsally concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1345. Caudal vertebra 3, spinous process, anteroposterior position relative to the posterior surface of the centrum, lateral view: does not extend behind the level of the posterior edge of the centrum (0), extends posterior to the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1346. Caudal vertebra 3, spinous process, anterior and posterior margins, lateral view: diverge from each other distinctly (0), divergence is indistinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1347. Caudal vertebra 3, spinous process, dorsal margin, form, lateral view: horizontal (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1348. Caudal vertebra 3, anterior interspinous ligament scar, anterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1349. Caudal vertebra 3, prezygapophysis, dorsal process, form (hooked condition), presence, lateral view: not posteriorly hooked (0), posteriorly hooked (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1350. Caudal vertebra 3, prezygapophysis, joint surface, orientation, anterior view: faces more medially than dorsally (0), faces equally dorsally and medially or more dorsally than medially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1351. Caudal vertebra 3, prezygapophysis, anterior end, expansion, lateral view: minor dorsoventral expansion (0), distinct dorsoventral expansion (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1352. Caudal vertebra 3, ridge that extends anteriorly from the transverse process to the prezygapophysis, form, lateral view: a ridge that anteriorly becomes a low process (0), an elevated knob (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1353. Caudal vertebra 3, transverse process, shape, dorsal view: hatchet shaped with a shallowly concave leading edge and a deeply concave trailing edge (0); paddle shaped, with a shallowly concave leading edge and a distally convex trailing edge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1354. Caudal vertebra 3, transverse process, distal end, shape, dorsal view: widens slightly (0), distinct expansion (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1355. Caudal vertebra 3, postzygapophyses, long axis, orientation, posterior view: steep dorsolateral to ventromedial (more lateral than ventral) (0); low angle, faces more fully ventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 4 (11 characters)

1356. Caudal vertebra 4, centrum, large centrally positioned neurovascular foramen, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1357. Caudal vertebra 4, prezygapophysis, anteroposterior orientation, lateral view: steep (~45 degrees) anterodorsal (0), low (less than 45 degrees) anterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1358. Caudal vertebra 4, prezygapophysis, dorsal process, form (hooked condition), presence, lateral view: not posteriorly hooked (0), posteriorly hooked (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1359. Caudal vertebra 4, prezygapophysis, joint surface, orientation, anterior view: steeply mediodorsally (more medial than dorsal) (0), low angle, equally medial and dorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1360. Caudal vertebra 4, spinous process, form, lateral view: distinctly narrow waist above the postzygapophyses (0), waist is indistinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1361. Caudal vertebra 4, anterior interspinous ligament scar, anterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1362. Caudal vertebra 4, transverse process, shape, dorsal view: hatchet shaped with a shallowly concave leading edge and a deeply concave trailing edge (0); paddle shaped, with a shallowly concave leading edge and a distally convex trailing edge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1363. Caudal vertebra 4, transverse process, orientation, anterior view: low (more lateral than dorsal), but distinct dorsolateral angle (0); very low dorsolateral angle, almost directly laterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1364. Caudal vertebra 4, transverse process, anteroposterior length, dorsal view: not longer than in the preceding vertebra (0), longer than in the preceding vertebra (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1365. Caudal vertebra 4, postzygapophyses, joint surface, posterior view: steeply ventromedially (more lateral than ventral) (0), not steep (equally ventral and lateral) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1366. Caudal vertebra 4, hyposphenes, orientation, posterior view: extend directly ventrally (0), extend ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 5 (23 characters)

1367. Caudal vertebra 5, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: centrum is longer than tall (0), centrum is as tall as long or taller than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1368. Caudal vertebra 5, centrum, relative depth of the anterior and posterior joint surfaces, anterior and posterior views: anterior joint surface is more deeply concave than the posterior joint surface (0), the joint surfaces are of equal depth (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1369. Caudal vertebra 5, centrum, large centrally positioned neurovascular foramen, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1370. Caudal vertebra vertebra 5, centrum, ventral margin, form, lateral view: shallowly dorsally concave (0), deeply dorsally concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1371. Caudal vertebra 5, prezygapophysis, dorsal process, form (hooked condition), presence, lateral view: not posteriorly hooked (0), posteriorly hooked (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1372. Caudal vertebra 5, prezygapophysis, anteroposterior orientation, lateral view: steep (~45 degrees) anterodorsal (0), low (less than 45 degrees) anterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1373. Caudal vertebra 5, prezygapophysis, joint surface, orientation, dorsal view: marginally in view, where the joint surface faces more medially than dorsally (0); widely exposed, where the joint surface faces more dorsally than medially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1374. Caudal vertebra 5, spinous process, anteroposterior position relative to the posterior surface of the centrum, lateral view: does not extend behind the level of the posterior edge of the centrum (0), extends posterior to the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1375. Caudal vertebra 5, anterior interspinous ligament scar, anterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1376. Caudal vertebra 5, posterior interspinous ligament scar, posterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1377. Caudal vertebra 5, posterior interspinous ligament scar, exposure, lateral view: marginally exposed (0), widely exposed (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1378. Caudal vertebra 5, spinous process, orientation, lateral view: steep posterodorsal (0), vertical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1379. Caudal vertebra 5, spinous process, mediolateral width, dorsal view: narrow and bladelike (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1380. Caudal vertebra 5, spinous process, position relative to the posterior edge of the centrum, lateral view: does not extend past the centrum (0), extends past the centrum (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1381. Caudal vertebra 5, spinous process, anteroposterior length relative to process of the preceding vertebra, lateral view: anteroposteriorly shorter (0), not distinctly anteroposteriorly shorter (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1382. Caudal vertebra 5, spinous process, dorsal margin, form, lateral view: convex (0), level (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1383. Caudal vertebra 5, transverse process, form, dorsal view: anteroposteriorly long and mediolaterally short (0), narrow and long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1384. Caudal vertebra 5, transverse process, relative position of the anterolateral and posterolateral corners, dorsal view: posterolateral corner is medial relative to the anterolateral corner (0), the corners are anteroposteriorly in line with each other (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1385. Caudal vertebra 5, transverse process, angle, anterior view: a low (more lateral than dorsal), but distinctly dorsolaterally extending angle (0); essentially extends laterally, where only the ventral margin shows a dorsolateral component (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1386. Caudal vertebra 5, flange between postzygapophysis and transverse process, presence, dorsal view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1387. Caudal vertebra 5, postzygapophyses, mediolateral width, caudal view: narrow (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1388. Caudal vertebra 5, postzygapophyses, joint surface, orientation, posterior view: steep ventrolateral (more lateral than ventral) (0), nearly directly ventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1389. Caudal vertebra 5, hyposphene, orientation, caudal view: extend ventrally (0), extend ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 6 (12 characters)

1390. Caudal vertebra 6, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: centrum is longer than tall (0), centrum is as tall as long or taller than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1391. Caudal vertebra 6, centrum, large centrally positioned neurovascular foramen, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1392. Caudal vertebra 6, spinous process, anteroposterior position relative to the posterior surface of the centrum, lateral view: does not extend behind the level of the posterior edge of the centrum (0), extends posterior to the centrum (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1393. Caudal vertebra 6, anterior interspinous ligament scar, anterodorsal bridge, anteroposterior length, lateral view: short (0), long (1).

Exemplars: AMNH FARB 5027 (0), FMNH PR2081 (1).

1394. Caudal vertebra 6, posterior interspinous ligament scar, posterodorsal bridge, anteroposterior length, lateral view: short (0), long (1).

Exemplars: AMNH FARB 5027 (0), FMNH PR2081 (1).

1395. Caudal vertebra 6, transverse process, posterolateral corner, form, dorsal view: sharply pointed (0), rounded (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1396. Caudal vertebra 6, transverse process, lateral margin, dorsal view: convex and the posterolateral corner is situated medially relative to the anterolateral corner (0), convex and the corners are in line with each other or the posterolateral corner is lateral to the anterolateral corner (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1397. Caudal vertebra 6, transverse process, posteromedial margin, form, dorsal view: deeply concave (0), shallowly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1398. Caudal vertebra 6, transverse process, posteromedial margin, medial extent, form, dorsal view: convex curve (0), shallowly concave (0).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1399. Caudal vertebra 6, flange between postzygapophysis and transverse process, presence, dorsal view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1400. Caudal vertebra 6, postzygapophyses, orientation, posterior view: steep ventrolateral (more lateral than ventral) (0), more ventral than lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1401. Caudal vertebra 6, hyposphene, orientation, posterior view: slightly ventrolaterally (0), laterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 7 [BMRP cast labeled as #9] (12 characters)

1402. Caudal vertebra 7, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: centrum is longer than tall (0), centrum is taller than long (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1403. Caudal vertebra 7, centrum, joint surfaces, depth, anterior and posterior views: anterior joint surface is deepest (0), joint surfaces are of equal depth (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1404. Caudal vertebra 7, spinous process, orientation, lateral view: distinctly posterodorsal (0), nearly vertical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1405. Caudal vertebra 7, spinous process, form, lateral view: anteroposteriorly long and dorsoventrally short (0), short and tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1406. Caudal vertebra 7, spinous process, form, dorsal view: anteroposteriorly long, mediolaterally narrow and bladelike (0); short and wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1407. Caudal vertebra 7, anterior interspinous ligament scar, exposure, lateral view: exposed along the upper half of the spinous process (0), exposed along the entire anterior edge of the spinous process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1408. Caudal vertebra 7, spinous process, posterior edge, lateral view: extends along a shallowly concave curve to the postzygapophysis (0), extends along a deeply concave curve to the postzygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1409. Caudal vertebra 7, transverse process, anterior edge, form, dorsal view: gently concave and nearly straight, with a minor anterolateral flare (0); distinctly concave with a distinct anterior flare (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1410. Caudal vertebra 7, transverse process, posterior edge, form, dorsal view: medial end is strongly convex (0), medial end is gently concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1411. Caudal vertebra 7, transverse process, dorsolateral orientation, anterior view: distinctly dorsolateral, but less than 45 degrees (0); extends directly laterally or at a very low dorsolateral angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1412. Caudal vertebra 7, joint surface of the postzygapophysis, orientation, lateral view: faces laterally such that there is no differentiation between joint surface and the hyposphene (0), faces ventrally with a distinct angle between the joint surface and the hyposphene (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1413. Caudal vertebra 7, hyposphene, orientation, posterior view: extends vertically (0), extends ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 8 [BMRP cast labeled as #7] (13 characters)

1414. Caudal vertebra 8, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: centrum is longer than tall (0), centrum is as tall as long (1), taller than long (2).

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Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1), FMNH PR2081 (2).

1415. Caudal vertebra 8, centrum, relative depth of the anterior and posterior joint surfaces, anterior and posterior views: anterior joint surface is more deeply concave than the posterior joint surface (0), the joint surfaces are of equal depth (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1416. Caudal vertebra 8, prezygapophysis, joint surface, orientation, dorsal view: marginally in view, where the joint surface faces more medially than dorsally (0); widely exposed, where the joint surface faces more dorsally than medially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1417. Caudal vertebra 8, flange between postzygapophysis and transverse process, presence, dorsal view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1418. Caudal vertebra 8, transverse process, orientation, anterior view: dorsolateral (0), lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1419. Caudal vertebra 8, transverse process, posteromedial flange, presence, dorsal view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1420. Caudal vertebra 8, transverse process, anterolateral and posterolateral corners, relative position, dorsal view: posterolateral corner is medial to the anterolateral corner (0), corners are anteroposteriorly in line with each other (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1421. Caudal vertebra 8, spinous process, mediolateral width, dorsal view: narrow and blade-like (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1422. Caudal vertebra 8, spinous process, shape, lateral view: anteroposteriorly long and dorsoventrally short (0), anteroposteriorly short and dorsoventrally tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1423. Caudal vertebra 8, spinous process, dorsal edge, form, lateral view: extends posterodorsally at a low angle (0), horizontal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1424. Caudal vertebra 8, spinous process, interspinous ligament scars, exposure, lateral view: anterior scar forms the anterodorsal corner of the process, posterior scar is marginally exposed (0); scars are exposed along nearly the entire height of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1425. Caudal vertebra 8, postzygapophysis, joint surface and hyposphene, orientation, posterior view: joint surface faces more lateral than ventral, hyposphene extends slightly ventrolaterally (0); joint surface faces ventrally, hyposphene extends steeply ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1426. Caudal vertebra 8, postzygapophyses, joint surface, form, posterior view: flares dorsally as a stout spike next to the base of the spinous process (0), dorsally flaring condition is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 9 [BMRP cast labeled as #8] (17 characters)

1427. Caudal vertebra 9, centrum, anteroposterior length to dorsoventral height ratio, lateral view: significantly longer than tall (0), length and height are nearly the same (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1428. Caudal vertebra 9, prezygapophysis, orientation, lateral view: steep anterodorsal (0), low anterodorsal, nearly horizontal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1429. Caudal vertebra 9, spinous process, height relative to preceding vertebra, lateral view: distinctly shorter (0), little or no difference in height (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1430. Caudal vertebra 9, spinous process, form, lateral view: anteroposteriorly long and dorsoventrally low (0), tall and narrow (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1431. Caudal vertebra 9, spinous process, interspinous ligament scars, exposure, lateral view: marginal (0), widely exposed (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1432. Caudal vertebra 9, spinous process, anterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1433. Caudal vertebra 9, spinous process, posterior margin, form, lateral view: extends uninterrupted posterodorsally (0), distinct angular concavity (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1434. Caudal vertebra 9, spinous process, mediolateral width, all views: narrow and bladelike (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1435. Caudal vertebra 9, spinous process, orientation, lateral view: posterodorsal (0), vertical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1436. Caudal vertebra 9, transverse process, anterior edge, form, dorsal view: convex (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1437. Caudal vertebra 9, transverse process, posteromedial flange, size, dorsal view: prominent and separated laterally from the posterior edge of the transverse process by a notch (0); not prominent, where the notch is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1438. Caudal vertebra 9, transverse process, dorsoventral position on the pedicle relative to the vertebral canal (notch for the intervertebral foramen), lateral view: at the midheight of the vertebral canal (0), at the dorsal edge of the canal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1439. Caudal vertebra 9, transverse process, orientation, anterior view: extends laterally (0), extends lightly ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1440. Caudal vertebra 9, postzygapophyses, position on the spinous process, lateral view: extends up a third of the height of the process (0), occupies the lower quarter of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1441. Caudal vertebra 9, postzygapophysis, differentiation between dorsal joint surface and hyposphene, posterior view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1442. Caudal vertebra 9, postzygapophysis, joint surface, orientation, posterior view: ventrolateral (0), ventral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1443. Caudal vertebra 9, postzygapophysis, form, posterior view: flares dorsally as a spur (0); extends to the side, not dorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 10 (10 characters)

1444. Caudal vertebra 10, centrum, anteroposterior length to dorsoventral height ratio, lateral view: significantly longer than tall (0), length is slightly longer than height (1), length and height are nearly the same (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1), AMNH FARB 5027 (2).

1445. Caudal vertebra 10, prezygapophysis, orientation, lateral view: anterodorsal (0), anterior (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1446. Caudal vertebra 10, prezygapophysis, differentiation from anterior process, medial view: present, a distinct groove separates the joint surface from the process (0); absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1447. Caudal vertebra 10, spinous process, dorsoventral height, lateral view: long and low (0), narrow and tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1448. Caudal vertebra 10, spinous process, dorsoventral height relative to preceding vertebra, lateral view: distinctly shorter (0), slightly shorter (1), same height (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (0), AMNH FARB 5027 (2).

1449. Caudal vertebra 10, spinous process, shape, lateral view: fan shaped (0), columnar (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1450. Caudal vertebra 10, spinous process, mediolateral width, all views: narrow and blade-like (0), wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1451. Caudal vertebra 10, spinous process, posterior interspinous ligament scar, lateral view: marginally exposed (0), widely exposed (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1452. Caudal vertebra 10, transverse process, posteromedial flange, form, dorsal view: distinct and separated laterally by a notch (0), notch is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1453. Caudal vertebra 10, postzygapophysis, junction with posterior edge of spinous process, lateral view: postzygapophysis extends posteroventrally from the spinous process (0), the processes are joined by a continuous edge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 11 (13 characters)

1454. Caudal vertebra 11, centrum, ratio of dorsoventral height to anteroposterior length, lateral view: the height is significantly lower than the length (0), the height is minimally lower than the length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1455. Caudal vertebra 11, centrum, length to height ratio relative to preceding vertebra, lateral view: longer and lower than the preceding vertebra (0), difference is subtle (1).

Exemplars: BMRP 2002.4.1, FMNH PR2081.

1456. Caudal vertebra 11, prezygapophysis, anterodorsal angle, lateral view: less than 45 degrees (0), 45 degrees or greater (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1457. Caudal vertebra 11, prezygapophysis, nonjoint anterior process, presence, lateral and medial views: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1458. Caudal vertebra 11, spinous process and postzygapophysis, position relative to posterior edge of the centrum, lateral view: posterodorsal corner of spinous process extends past centrum (0), posterodorsal corner of spinous process and postzygapophysis extend past centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1459. Caudal vertebra 11, spinous process, shape, lateral view: anteroposteriorly long (0), intermediate (1), tall and narrow (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1), FMNH PR2081 (2).

1460. Caudal vertebra 11, spinous process, form, lateral view: fan shaped (0), columnar with a vertical anterior margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1461. Caudal vertebra 11, spinous process, connection to prezygapophysis, lateral view: distinct web connects the structures (0), web absent and the structures are separated by a notch (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1462. Caudal vertebra 11, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1463. Caudal vertebra 11, spinous process, interspinous ligament scars, exposure, lateral view: marginally exposed (0), widely exposed (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1464. Caudal vertebra 11, transverse process, base, dorsoventral position relative to the vertebral canal, lateral view: ventral margin (0), dorsal margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1465. Caudal vertebra 11, transverse process, distal end, form, dorsal view: slightly expanded anteroposteriorly (0), anteroposteriorly expanded and backswept into a hook-like process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1466. Caudal vertebra 11, connection between postzygapophysis and spinous process, lateral view: connected by a ridge (0), not connected (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 12 (18 characters)

1467. Caudal vertebra 12, centrum, ratio of dorsoventral height to anteroposterior length, lateral view: the height is significantly lower than the length (0), the height is minimally lower than the length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1468. Caudal vertebra 12, prezygapophysis, anterodorsal height relative to the postzygapophysis, lateral view: extends dorsal to the level of the postzygapophysis (0), does not extend dorsal to the level of the postzygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1469. Caudal vertebra 12, prezygapophysis, length relative to length of the centrum, lateral view: greater than half the length of the centrum (0), half the length of the centrum or less (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1470. Caudal vertebra 12, ridge that extends from the prezygapophysis to the postzygapophysis across the base of the spinous process, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1471. Caudal vertebra 12, prezygapophyses, angle of divergence from each other, anterior and dorsal views: more anteriorly than laterally (0), equally lateral and anterior (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1472. Caudal vertebra 12, spinous process, shape, lateral view: fan-shaped (0), vertical anterior margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1473. Caudal vertebra 12, spinous process, dorsoventral height relative to the prezygapophysis, lateral view: short (0), tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1474. Caudal vertebra 12, spinous process, height relative to preceding vertebra, lateral view: same height (0), shorter (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1475. Caudal vertebra 12, spinous process, dorsal margin, form, lateral view: subtly concave (0), level (1).

Exemplars: BMRP 2002.4.1 (0), AMNH FARB 5027 (1).

1476. Caudal vertebra 12, spinous process, anterior interspinous ligament scar, anterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1477. Caudal vertebra 12, spinous process, posterior interspinous ligament scar, posterodorsal bridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1478. Caudal vertebra 12, spinous process, posterior margin, lateral view: extends to postzygapophysis without interruption (0), deep notch separates the zygapophysis from the posterior edge of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1479. Caudal vertebra 12, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1480. Caudal vertebra 12, pedicle, posteroventral edge, flange, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1481. Caudal vertebra 12, transverse process, orientation, dorsal view: lateral (0), posterolateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1482. Caudal vertebra 12, transverse process, orientation, anterior view: ventrolateral (0), lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1483. Caudal vertebra 12, transverse process, posterolateral margin, orientation, dorsal view: extends more anteriorly than laterally (0), extends more laterally than anteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1484. Caudal vertebra 12, transverse process, posteromedial flange, size, dorsal view: prominent (0), small (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 13 (14 characters)

1485. Caudal vertebra 13, centrum, ratio of dorsoventral height to anteroposterior length, lateral view: the height is significantly lower than the length (0), the height is minimally lower than the length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1486. Caudal vertebra 13, centrum, posterior joint surface, form, posterior view: tapers dorsally (0), dorsal edge is flat and wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1487. Caudal vertebra 13, prezygapophysis, anterodorsal height relative to the postzygapophysis, lateral view: extends dorsal to the level of the postzygapophysis (0), does not extend dorsal to the level of the postzygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1488. Caudal vertebra 13, prezygapophysis, length relative to length of the centrum, lateral view: greater than half the length of the centrum (0), half the length of the centrum or less (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1489. Caudal vertebra 13, prezygapophysis, orientation, lateral view: less than 45 degrees (0), 45 degrees or greater (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1490. Caudal vertebra 13, prezygapophysis, anterodorsal height relative to the spinous process, lateral view: closely approaches the level of the dorsal edge of the spinous process (0), far ventral to the dorsal edge of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1491. Caudal vertebra 13, prezygapophyses, divergence of contralateral zygapophyses, dorsal view: diverge at a low angle, where they extend more anteriorly than laterally and only minimally diverge from each other (0); diverge at a high angle, where the zygapophyses extend nearly equally anteriorly and laterally to diverge from each other at a high angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1492. Caudal vertebra 13, spinous process, dorsoventral height relative to that of the preceding vertebra, lateral view: shorter (0), same height (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1493. Caudal vertebra 13, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1494. Caudal vertebra 13, spinous process, dorsal margin, form, lateral view: not concave (0), distinctly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1495. Caudal vertebra 13, transverse process, orientation, dorsal view: extends directly laterally (0), extends posterolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1496. Caudal vertebra 13, transverse process, posterior margin, form, dorsal view: gently convex (0), deeply concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1497. Caudal vertebra 13, transverse process, lateral end, form, dorsal view: does not expand anteroposteriorly (0), expands anteroposteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1498. Caudal vertebra 13, centrum, posterior joint surface, dorsal margin, form, posterior view: narrow and dorsally convex (0), wide and flattened (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 14 (19 characters)

1499. Caudal vertebra 14, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: several times longer than tall (0), slightly longer than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1500. Caudal vertebra 14, centrum, shape, anterior view: teardrop shaped, with a wide dorsal region and a tapering ventral region (0); cartouche shaped, with wide dorsal and ventral regions (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1501. Caudal vertebra 14, centrum shape, posterior view: mediolaterally narrow (0), mediolaterally wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1502. Caudal vertebra 14, centrum, anteroventral and posteroventral corners, form, lateral view: pedicle-like processes are absent (0), pedicle-like joint surfaces for the hemal arches are present and disrupt the ventral margin of the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1503. Caudal vertebra 14, centrum, anterior and posterior joint surfaces, relative depths, anterior and posterior views: anterior joint surface is deepest (0), equal depth (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1504. Caudal vertebra 14, prezygapophysis, dorsoventral height relative to the spinous process, lateral view: taller than the process (0), shorter than the spinous process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1505. Caudal vertebra 14, prezygapophysis, dorsoventral height relative to the postzygapophysis, lateral view: taller than the postzygapophysis (0), approximately the same height (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1506. Caudal vertebra 14, prezygapophysis, length relative to centrum, lateral view: greater than half the length of the centrum (0), approximately half the length of the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1507. Caudal vertebra 14, prezygapophysis, orientation, lateral view: less than 45 degrees (0), greater than 45 degrees (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1508. Caudal vertebra 14, prezygapophysis, form, lateral view: long and slender (0), short and deep (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1509. Caudal vertebra 14, prezygapophysis, joint surface, emargination of the anterior margin of the zygapophysis, lateral view: emargination is absent (0), emargination is present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1510. Caudal vertebra 14, prezygapophyses, divergence of contralateral zygapophyses, dorsal view: diverge at a low angle, where they extends more anteriorly than laterally and only minimally diverge from each other (0); diverge at a high angle, where the zygapophyses extend nearly equally anteriorly and laterally to diverge from each other at a high angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1511. Caudal vertebra 14, prezygapophyses, medial surface, exposure, dorsal view: not widely exposed to view (0), widely exposed to view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1512. Caudal vertebra 14, transverse process, form, dorsal view: short anterolaterally extending spike (0), long laterally extending tab (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1513. Caudal vertebra 14, transverse process, orientation, dorsal view: anterolateral (0), lateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1514. Caudal vertebra 14, transverse process, form relative to that of the preceding vertebra, dorsal view: greatly reduced (0), intermediate in form between preceding and succeeding vertebrae (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1515. Caudal vertebra 14, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1516. Caudal vertebra 14, spinous process, proximity to the prezygapophysis, lateral view: widely separated (0), close together (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1517. Caudal vertebra 14, spinous process, anterior margin, orientation, lateral view: vertical (0), posterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 15 (12 characters)

1518. Caudal vertebra 15, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: several times longer than tall (0), slightly longer than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1519. Caudal vertebra 15, centrum, anteroventral corner, form, lateral view: pedicle like process is absent (0), pedicle-like joint surface for the hemal arch is present and it disrupts the ventral margin of the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1520. Caudal vertebra 15, prezygapophysis, anteroposterior length relative to the centrum length, lateral view: greater than half the centrum length (0), approximately half the centrum length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1521. Caudal vertebra 15, prezygapophysis, anterodorsal orientation, lateral view: low, less than 45 degrees (0); steep, approximately 45 degrees (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1522. Caudal vertebra 15, prezygapophysis, joint surface of the postzygapophysis, interruption of the anterior margin of the prezygapophysis, lateral view: does not emarginate the anterior margin (0), emarginates the anterior margin as a prominent convexity (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1523. Caudal vertebra 15, prezygapophyses, divergence of contralateral zygapophyses, dorsal view: diverge at a low angle, where they extend more anteriorly than laterally and only minimally diverge from each other (0); diverge at a high angle, where the zygapophyses extend nearly equally anteriorly and laterally to diverge from each other at a high angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1524. Caudal vertebra 15, prezygapophysis, medial surface, orientation, anterior and dorsal views: faces more medially than dorsally (0), faces more dorsally than medially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1525. Caudal vertebra 15, spinous process, dorsoventral height, lateral view: dorsoventrally short (longer than tall) (0), tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1526. Caudal vertebra 15, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1527. Caudal vertebra 15, spinous process, anterior margin, orientation, lateral view: vertical (0), posterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1528. Caudal vertebra 15, transverse process, form, dorsal view: a low, laterally extending triangular ridge (0); an anterolaterally extending and distinct process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1529. Caudal vertebra 15, postzygapophysis, proximity to posterior edge of spinous process, lateral view: lateral to process (0), extends behind the level of the process and the structures are separated by a notch (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1530. Caudal vertebra 15, postzygapophysis, position relative to the spinous process, lateral view: apposed to the spinous process (0), extends posterolaterally away from the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CAUDAL VERTEBRA 16 (14 characters)

1531. Caudal vertebra 16, centrum, ratio of anteroposterior length to dorsoventral height, lateral view: several times longer than tall (0), slightly longer than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1532. Caudal vertebra 16, centrum, anteroventral and posteroventral corners, form, lateral view: pedicle-like processes are absent (0), pedicle-like joint surfaces for the hemal arches are present and disrupt the ventral margin of the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1533. Caudal vertebra 16, centrum, anterior joint surface, shape, anterior view: does not taper ventrally (0), tapers ventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1534. Caudal vertebra 16, prezygapophysis, anteroposterior length relative to the centrum length, lateral view: greater than half the centrum length (0), approximately half the centrum length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1535. Caudal vertebra 16, prezygapophysis, anterodorsal orientation, lateral view: low, less than 45 degrees (0); steep, approximately 45 degrees or greater (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1536. Caudal vertebra 16, prezygapophysis, joint surface of the postzygapophysis, interruption of the anterior margin of the prezygapophysis, lateral view: does not emarginate the anterior margin (0), emarginates the anterior margin as a prominent convexity (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1537. Caudal vertebra 16, prezygapophysis, height relative to the spinous process, lateral view: taller than spinous process (0), spinous process is taller than the prezygapophysis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1538. Caudal vertebra 16, contralateral prezygapophyses, divergence, dorsal view: low angle (0), diverge widely such that anteriorly they are widely separated (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1539. Caudal vertebra 16, spinous process, anterior margin, orientation, lateral view: vertical (0), posterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1540. Caudal vertebra 16, spinous process, posterior extent relative to centrum, lateral view: extend a short distance past posterior end of the centrum (0), extend a great distance past the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1541. Caudal vertebra 16, spinous process, form relative to preceding vertebra, lateral view: same size, extends further anteriorly (0), smaller and does not extend further anteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1542. Caudal vertebra 16, spinous process, lateral fossa, ventral margin, lateral view: ventral margin clearly defined by a ridge that extends between the zygapophyses and across the base of the spinous process (0), ridge is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1543. Caudal vertebra 16, spinous process and postzygapophysis, posterior extent relative to the posterior edge of the centrum, lateral view: extend a short distance past the centrum (0), extend approximately a quarter of the length of the spinous process past the centrum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1544. Caudal vertebra 16, postzygapophysis, orientation, posterior view: nearly horizontal (0), dorsolateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

SCAPULOCORACOID (3 characters)

NOTE: The joint surface for the scapula marks the dorsal margin of the bone, and the glenoid marks its posterior edge. These orientations differ from that for the scapula.

1545. Scapulocoracoid, scapulocoracoid suture, form, lateral view: the bones are flat across the suture (0); the bones join along a distinct anteroposteriorly extending ridge that divides the anterior third of the acromial region into dorsal and ventral compartments (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1546. Scapulocoracoid, acromial region, lateral surface, form, lateral view: the acromial region is concave in vertical section, where it is most deeply concave on the coracoid where it is bounded ventrally by a distinct ridge that extends anteroposteriorly along the coracoid, whereas a subtle ridge on the scapula marks its dorsal boundary (0); the fossa is most deeply inset on the scapula, where it is bounded by a subtle, anterodorsally extending convexity, whereas the fossa fades ventrally over the acromial region of the coracoid (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1547. Scapulocoracoid, curvature, form, anterior and posterior views: continuous curve across scapula and coracoid, forming an arch (0); sigmoid curve where the laterally convex curvature of the scapula abruptly straightens at the coracoid, forming a handlebar-like contour (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

SCAPULA (22 characters)

NOTE: Orientation is with the long axis of the bone held horizontally and with the acromion pointing dorsally. Ergo, the acromion extends dorsally from the dorsal edge of the bone whereas, opposite this, the glenoid extends ventrally from the ventral edge of the bone. The joint surface for the coracoid marks the anterior end of the bone, whereas the dilated distal end of the shaft is at the posterior extremity of the bone.

1548. Scapula, glenoid, width of the joint surface relative to the shaft, ventral view: as wide as the shaft (0), narrower than the shaft (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1549. Scapula, glenoid, anterolateral corner, width, ventral view: does not widen toward the coracoid (0), widens toward the coracoid (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1550. Scapula, lip of glenoid, emergence from ventral edge of shaft, form, lateral view: the lip extends at a low anteroventral angle from the shaft such that the structures grade into each other along a curve (0), lip extends abruptly from the shaft at a sharp angulation such that the structures are separated by an abrupt angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1551. Scapula, acromion, medial surface, form, medial view: concave in anteroposterior section (0), convex in anteroposterior section (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1552. Scapula, acromion, medial surface, vertical ridge, presence, medial view: absent, the medial surface is flat (0); present, widens as it extends dorsally to the dorsal edge of the acromion (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1553. Scapula, acromion, posterodorsal edge, process, presence, lateral and medial views: absent, the posterodorsal corner of the acromion is continuous and not interrupted by a notch that enhances a stout emargination in acromion (0); notch and emargination are present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1554. Scapula, acromion, dorsal edge, texture, form: subtly coarse (0), distinctly rugose (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1555. Scapula, acromion, dorsal edge, peak, anteroposterior position, lateral and medial views: positioned anteriorly, closer to the coracoid than to the posterior edge of the acromion (0); positioned posteriorly, closer to the posterior edge of the acromion than to the coracoid (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1556. Scapula, shaft, proximal end adjacent to acromion, dorsal edge, form, dorsal view: sharp, blade-like and extends along the dorsolateral edge of the bone (0); wide and along dorsolateral edge (1); wide and extends along the midwidth of the dorsal surface (2).

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1), FMNH PR2081 (2).

1557. Scapula, shaft, region of maximum curvature, dorsal view: anterior, toward the acromial region (0); posterior, distally away from the acromial region (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1558. Scapula, shaft, cross section toward the acromial region, shape: triangular (0), cylindrical (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: The *triangular* cross section is produced by a prominent, longitudinal strut on the medial surface that extends along the long axis of the scapular blade that separates it into dorsal and ventral compartments. This strut and compartmentalization is not seen in the adult condition, where the medial surface is uniformly convex.

1559. Scapula, shaft, lateral surface toward acromion, form, lateral view: subtly concave in dorsoventral cross section, becoming convex distally along the shaft (0); lateral surface is convex throughout (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1560. Scapula, shaft, dorsal edge toward the acromion, texture, medial view: coarse as it extends toward acromion (0), smooth between shaft and acromion (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1561. Scapula, shaft, muscle scar along dorsal edge, distinctiveness, medial view: sharply excavated (0), indistinct (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1562. Scapula, shaft, ventral edge, texture, medial view: coarsest toward the glenoid region, smooth toward posterior end of shaft (0); smooth toward glenoid, coarse toward posterior end of shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1563. Scapula, ventral edge, convexity, presence, lateral view: vanishingly subtle muscle scar along the ventral edge (0); scar is a relatively distinct convexity along the ventral edge of the bone, located a short distance distal to the glenoid (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: This scar is approximately the distance of the short axis of the acromion process from the glenoid.

1564. Scapula, shaft, waist between acromion and flattened region of shaft, distinctiveness, lateral view: the waist is a distinct narrow region (0), indistinct such that the proximal region of the shaft is relatively dorsoventrally tall and does not distinctly widen into the flattened distal region of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1565. Scapula, shaft, ridge on lateral surface of proximal end of expanded region, presence, lateral view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0) FMNH PR2081 (1).

1566. Scapula, shaft, curvature from acromial region, dorsal view: the shaft extends in nearly a straight line from the acromial region (0); the shaft curves distinctly laterally, then medially from the acromial region (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1567. Scapula, shaft, mediolateral width, form, dorsal view: the shaft tapers in width as it extends from the acromial region (0), the shaft maintains a uniform width as it extends from the acromial region and it only gradually tapers distally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1568. Scapula, shaft, ventral surface adjacent to glenoid, orientation, ventral view: ventral surface extends sharply dorsomedially from the ventral edge of the shaft (0); ventral surface is wide, coarsened by a muscle scar, and faces ventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1569. Scapula, shaft, medial surface, form, medial view: the medial surface is proximally convex, but progressively flattens distally (0); the medial surface is convex throughout, except distally where it widens and flattens as it fans out on each side of the convex medial surface of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

CORACOID (19 characters)

NOTE: The joint surface for the scapula marks the dorsal margin of the bone, and the glenoid marks its posterior edge. These orientations differ from that for the scapula.

1570. Coracoid, anterior margin, orientation, lateral view: vertical for some extent (0), mostly vertical (1).

Exemplars: BMRP 2002.4.1 (0), UWBM 99000 (1).

1571. Coracoid, anteroventral margin, form, lateral view: subtly convex (0), subtly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1572. Coracoid, coracoid foramen, orientation, lateral view: extends from posterolateral to anteromedial (0), extends from anterolateral to posteromedial (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1573. Coracoid, coracoid foramen, dorsoventral position relative to the glenoid, lateral view: dorsal, where a straight line drawn that is drawn horizontally at the dorsal edge of the foramen intersects the midheight of the glenoid (0); ventral, where the line intersects the ventral edge of the glenoid (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1574. Coracoid, glenoid, orientation, lateral view: the glenoid extends subhorizontally (more posterior than ventral) from the bone (0), the glenoid extends steeply posteroventrally (more ventral than posterior) from the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1575. Coracoid, glenoid, ventral margin, width and form, posterior view: wide and horizontally oriented (0), broadly tapering (1), narrow and tapering (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 002 (1), FMNH PR2081 (2).

1576. Coracoid, glenoid, separation from coracoid process, distinctiveness, lateral view: the glenoid is not sharply differentiated from the coracoid process, where a distinct ridge extends from the dorsolateral edge of the process to the ventrolateral corner of the glenoid (0); the glenoid and process are sharply differentiated, and the ridge that extends to the ventrolateral corner of the glenoid is absent (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: The ridge that is seen in subadults also produces an abrupt plane change between the flat lateral surface of the coracoid and the posteriorly-facing posterodorsal surface of the coracoid process. This region in adults is convex in horizontal section and lacks the plane change, instead having the form of a convex posterodorsal surface below the glenoid.

1577. Coracoid, low ridge that extends anteriorly from the biceps tubercle to the anterior edge of the bone, presence, lateral view: present, dividing the bone into distinct dorsal and

ventral compartments and is represented by a thickening in the anterior edge of the bone when viewed edge-on (0); absent, where the bone is a continuous concavoconvex surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1578. Coracoid, ventral margin, form, ventral view: uniformly narrow and subtly coarse (0), extremely wide and rugose (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1579. Coracoid, coracoid process, ridge along dorsolateral edge, form, lateral view: subtle, smooth ridge (0); massive, coarse ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1580. Coracoid, region between biceps tubercle and glenoid, form, lateral view: deeply concave in vertical section (0), subtly concave to convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1581. Coracoid, ventral half of bone, form, lateral view: divided into anterior and posterior concave compartments by a low, ventrally extending ridge (0); entire ventral half of bone is convex anteroposteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1582. Coracoid, region between the glenoid and the coracoid foramen, form, medial view: concave (0), shallowly concavoconvex (1), convex (2).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

1583. Coracoid, coracoid process, length, depth and curvature, lateral and medial views: relatively slender and not distally recurved (0), stout and distally recurved (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1584. Coracoid, medial fossa between coracoid foramen and the anterior edge of the bone, medial view: fossa extends anterodorsally to the anterior edge of the bone (0); fossa does not extend to the anterior edge of the bone, and is separated from it by a low ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1585. Coracoid, coarse and flattened ventral and posteroventral edge of the bone, position, medial view: confined to the flattened ventral edge of the bone (0), coarse rugosities extend onto the ventromedial and posteromedial surfaces of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1586. Coracoid, medial fossa that covers the posteroventral quadrant of the bone, anterior edge, distinctiveness, medial view: anterior edge of the fossa is indistinct and untraceable (0); sharply inset, distinct, and vertically extending anterior margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1587. Coracoid, medial ridge that extends vertically between the coracoid foramen and the medial fossa that covers the posteroventral quadrant of the bone, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1588. Coracoid, medial tubercle located anteroventral to the coracoid foramen and above the anteroventral corner of the coracoid, presence, medial view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

HUMERUS (8 characters)

1589. Humerus, proximodistal length: equal to or less than 30 cm (0), nearly 40 cm (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1590. Humerus, deltopectoral crest, angle at which it extends from the shaft, anterior and proximal views (Parks, 1928): steep (0), low (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1591. Humerus, surface between deltopectoral crest and head, cranial surface, form: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1592. Humerus, proximal half of bone, width relative to the distal half, anterior view: not greatly widened relative to the distal half (0), greatly widened relative to the distal half (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1593. Humerus, deltopectoral crest, deltoid muscle scar, distal end, form and texture, lateral view: shallow coarse fossa (0), deep fossa encircling a coarse ridge (1), uniformly convex and coarse (2), region is convex and coarse (3).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), RTMP 1981.006.0001 (2), FMNH PR2081 (3).

1594. Humerus, deltopectoral crest, distal end, position, cranial view: extends onto lateral edge of bone (0), distally extends medial to the lateral edge (onto cranial surface) of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1595. Humerus, deltopectoral crest, proximal extent: crest does not extend proximally (0), extends proximally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1596. Humerus, distal condyles, distal view: craniocaudally narrow (0), craniocaudally wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

ILIUM (4 characters)

1597. Ilium, preacetabular blade, anterior tip above ventral preacetabular hook, scar of the iliotibialis, distinctiveness, lateral view (Brochu, 2003): indistinct (0), a distinct rugosity (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1598. Ilium, scar of iliotibialis 2, anterior end ramification, number of ramifications, lateral view (Carrano and Hutchinson, 2002): ramifies into two scars (0), ramifies into three scars (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1599. Ilium, scar of iliofibularis, posterior extent, semicircular line, presence, lateral view (Carrano and Hutchinson, 2002): absent (0), present (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1600. Ilium, cuppedicus fossa, exposure, lateral view: widely exposed to lateral view (0), only the proximal end is exposed to view (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1601. Ilium, cuppedicus fossa, origin of the iliofemoralis internus, extent, lateral view: extensive, the fossa is dominant in covering most of the pubic peduncle and the dorsal bounding ridge reaches the supra-acetabular crest (0); reduced, where the pubic peduncle is dominant over the small, anterodorsally positioned fossa and the dorsal bounding ridge does not reach the supracetabular crest (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1602. Ilium, rostradorsal notch, dorsoventral position, lateral view: at the rostradorsal corner of the bone (0), below the midheight of the bone (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1603. Ilium, postacetabular process, ventral margin form, lateral view: dorsally concave (0), straight to subtly convex (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1604. Ilium, postacetabular fossa, lateral surface, form in vertical section, lateral view: concave to flat (0), strongly convex (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: The *postacetabular fossa* refers to the lateral surface of the postacetabular process; this corresponds to the region where the flexor tibialis externus muscle is hypothesized to originate (Carrano and Hutchinson, 2002).

PUBIS (3 characters)

1605. Pubis, pubic apron, form, posterior view: proximal end does not flare posteriorly and does not extend posterodorsally onto shaft as a sharp ridge (i.e., low ridge) (0), flares posteriorly and extends posterodorsally along shaft as a sharp ridge (1).
Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1606. Pubis, pubic apron, form, anterior view: aprons of each side abut and form a flat surface that is confluent with the flat anterior surface of the shafts (i.e., the aprons do not extend posteromedially) (0), extends posteromedially away from the anterior surface of the shaft, forming a deep concavity between sides (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1607. Pubis, shaft between pubic apron and boot, horizontal cross section: triangular with a medially pointing apex (0), oval with a posteromedial to anterolateral long axis (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1608. Pubis, pubic boot, posterior ramus, anterior half, dorsal margin, form, lateral view: convex (0), level before extending posteroventrally toward its tip (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

1609. Pubis, pubic boot, posterior ramus, lateral surface, anteroventrally extending ridge, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1).

ISCHIUM (9 characters)

1610. Ischium, differentiation between the iliac peduncle and the posterior margin of the bone, lateral view: indistinct (0); distinct such that the iliac peduncle is a distinct, dorsally-extending stalk (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1611. Ischium, obturator process, ventral margin, form, lateral view: dorsally concave (0), subtly convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1612. Ischium, angulation between posterior margin of body (region with semicircular scar) and posterior shaft, lateral view: subtle (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1613. Ischium, semicircular scars, number, lateral view: one, the primary scar bounded laterally by the thick ridge (0); two, the primary scar and a secondary scar immediately posteroventral to it that is narrow, shallower, and not bounded laterally by a ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: It is unclear if the secondary, posteroventrally situated semicircular scar corresponds to the internal tibial flexor 3 or to the femoral adductor 2. Given the presence of a long scar on the lateral surface of the proximal end of the shaft that almost certainly corresponds to the adductor (Carrano and Hutchinson, 2002), it is more probable that the secondary scar corresponds to the flexor.

1614. Ischium, posterior shaft, connection to obturator process, lateral view: the shaft is prominent and does not grade immediately into the obturator process (i.e., proximally it is a prominent ridge) (0), the shaft almost immediately grades into the obturator process (i.e., proximally it is not differentiated as a prominent ridge) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1615. Ischium, obturator process, fossa, presence, lateral view: shallow fossa bounded anteriorly by a narrow ridge (0), the anterior end of the process is depressed by a relatively deep

fossa that is bounded anteriorly by a distinct vertical ridge that extends along the anterior margin of the process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: It is possible that the ridge and fossa correspond to the origin of the femoral adductor 1 (Carrano and Hutchinson, 2002).

1616. Ischium, posterior shaft, proximal end, muscle scar, presence, lateral view: absent, the proximal end of the shaft that connects to the obturator process is convex and coarse (0); present, a coarse and anteroposteriorly long muscle scar flattens and excavates the lateral surface of the proximal end of the shaft, and a low, but distinct ridge bounds the scar ventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: This scar almost certainly corresponds to the femoral adductor 2 (Carrano and Hutchinson, 2002).

1617. Ischium, posterior end of shaft, mediodorsal edge, form, lateral view: mediodorsal edge flares dorsally above the columnar shaft along its distal third to half as a distinct, longitudinal ridge (0); the mediodorsal edge does not flare dorsally and a ridge is not seen (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1618. Ischium, posterior shaft, medioventral edge, form, lateral view: medioventral edge flares ventrally to form a long, flange-like ridge that extends along the distal half of the shaft (0); the ridge is low, wide, and coarse, not deep, thin, and flange-like, and limited to the distal third of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

FEMUR (6 characters)

1619. Femur, circumference to length ratio: less than 44% (0), greater than or equal to 44% (1).

Exemplars: LACM 150167 (0), RSM 2523.8 (1).

1620. Femur, greater trochanter, insertion scar for the puboischiofemoralis externus, form, lateral view (Carrano and Hutchinson, 2002): low, indistinct convexity (0); distinct, bulbous, vertically oriented ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1621. Femur, accessory trochanter, distinctiveness, lateral view (Carrano and Hutchinson, 2002): indistinct (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: The accessory trochanter represents the insertion for the cranial and medial iliotrochanteric or for the external puboischiofemoral 2 (Carrano and Hutchinson, 2002).

1622. Femur, trochanteric shelf (insertion for the iliofemoralis externus muscle), form, lateral view (Carrano and Hutchinson, 2002): a low swelling with an indistinct subordinate topography (0), a large and coarse swelling with a distinct topography (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1623. Femur, insertion for the ischiotrochanteric muscle, form, lateral view (Carrano and Hutchinson, 2002): a low, posterolaterally positioned ridge at the greater trochanter (0); a massive, coarse ridge that occupies the posterolateral corner of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1624. Femur, distal tuberosity, form (Brochu, 2003): shallow and relatively smooth (0); intermediate in depth, coarse and pitted at dorsal end (1); deep and coarse (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

Tibia (21 characters)

1625. Tibia, circumference to length ratio: equal to or less than 30% (0), greater than 30% and less than 45% (1), equal to or greater than 51% (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), RSM 2523.8 (2).

1626. Tibia, shaft, curvature, anterior view: straight or subtly bowed (0); distinctly bowed laterally, where the medial edge is concave and the lateral edge is convex (1).

Exemplars: DDM 35.1 (0), FMNH PR2081 (1).

1627. Tibia, shaft, posterolateral surface adjacent to the fibular crest, ridges, presence, posterior view: ridges are absent (0); a series of parallel, ventrolaterally to dorsomedially extending ridges are present (1).

Exemplars: DDM 35.1 (0); BMRP 2002.4.1 (1).

Note: The ridges mark the insertion of the internal tibial flexor 1 (Carrano and Hutchinson, 2002).

1628. Tibia, medial cnemial crest, distal extensor groove, depth of incision into crest, anterolateral view (Carrano and Hutchinson, 2002): a shallow groove (0), a deeply incised cleft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1629. Tibia, malleoli, mediolateral prominence, anterior view: lateral malleolus is more prominent than the medial malleolus (0), malleoli extend equally from the shaft (1), the medial malleolus juts more prominently (2). **ORDERED**

Exemplars: DDM 35.1 (0); BMRP 2002.4.1 (1). FMNH PR2081 (2).

1630. Tibia, ventral margin, condition, anterior and posterior views: gently concave between the malleoli (0), deeply concave between the malleoli (1).

Exemplars: DDM 35.1 (0); BMRP 2002.4.1 (1).

1631. Tibia, lateral malleolus, joint surface for the fibula, width: mediolaterally very narrow (0), mediolaterally very wide (1).

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1).

1632. Tibia, lateral malleolus, proximal end that extends onto the posterior surface of the shaft, condition, posterior view: mediolaterally narrow and coarse ridge (0), mediolaterally wide and very coarse ridge (1).

Exemplars: DDM 35.1 (0); BMRP 2002.4.1 (1).

1633. Tibia, flange above the coarse and ridge-like posterodorsal corner of the lateral malleolus, form, posterior view: faces distinctly laterally (0), a concave web that faces posterolaterally (1), a deeply excavated web that faces nearly directly posteriorly (2).

ORDERED

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1), DDM 35.65 (2).

1634. Tibia, medial malleolus, ventral margin, form, medial view: horizontally oriented (0); strongly convex, where it extends ventrally as an inverted triangle (1); weakly convex, broadly triangular (2). **ORDERED**

Exemplars: DDM 35.1 (0), FMNH PR2081 (1), MOR 1125 (2).

1635. Tibia, shaft, medial surface at junction of shaft and medial malleolus, form, medial view: cylindrical (0), gently concave (1).

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1).

1636. Tibia, shaft, ventral end of strut-like posterior surface, form, posterior view: a distinct and narrow ridge concentrated above the lateral half of the medial malleolus (0), indistinct and medially and laterally widened (1).

Exemplars: DDM 35.1 (0), DDM 35.65 (1).

1637. Tibia, lateral malleolus, posterior surface, form, posterior view: distinctly concave (0); gently convex, especially in vertical section (1).

Exemplars: DDM 35.1 (0), DDM 35.65 (1).

1638. Tibia, posterolateral surface, tubercle, approximately 1/5th up the shaft, presence, posterior view: absent (0), present (1).

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1).

1639. Tibia, lateral malleolus, vertical cleft in lateral surface of malleolus, depth, lateral view: shallow (0); deep, where its dorsal extent cuts deeply between the malleolus and the lateral edge of the shaft, that abuts the fibula posteriorly, onto the posterior surface of the bone, producing a deep trochlea (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1640. Tibia, posterior surface, arcuate sulcus that extends from dorsolaterally to ventromedially across the posterior surface of the shaft, extends toward the ridge that extends ventrally to the lateral half of the medial malleolus, approximately 1/5th up the shaft, presence, posterior view: present (0), absent (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1641. Tibia, joint surface for the fibula, dorsal extent, anterior view: stops below halfway up the joint surface for the astragalus (0), stops at or above the midheight of the joint surface for the astragalus (1).

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1).

1642. Tibia, vertical ridge that separates the medial part of the joint surface for the astragalus from the lateral part, presence, anterior view: very indistinct to absent (0); present, distinct, and deeply undercut on its medial side (1).

Exemplars: DDM 35.1 (0), DDM 35.65 (1).

1643. Tibia, joint surface for the astragalus, dorsomedial margin, angle, anterior view: steep, where it extends dorsolaterally at an angle much greater than 45 degrees, but less than 90 degrees (0); low, where it extends dorsolaterally at an angle of approximately 45 degrees (1).

Exemplars: DDM 35.1 (0), DDM 35.65 (1).

1644. Tibia, accessory joint surface for the fibula above that for the astragalus, presence and form: almost certainly absent, aside from a coarse texture along the anterolateral margin of the shaft (0); a distinct, flat, and anterolaterally facing facet on the anterolateral edge of the bone (1).

Exemplars: DDM 35.1 (0), BMRP 2002.4.1 (1).

1645. Tibia, joint surface for the astragalus adjacent to that for the fibula, form, anterior view: deeply concave (0), very gently concave and convex in its midregion (1). **Exemplars:** DDM 35.1 (0), DDM 35.65 (1).

1646. Tibia, medial part of the joint surface for the astragalus form, anterior view: gently concave (0), deeply concave (1).

Exemplars: DDM 35.1 (0), DDM 35.65 (1).

FIBULA (40 characters)

1647. Fibula, ratio of midheight length to total height: equal to or less than 5% (0), greater than 5% (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1648. Fibula, overall form, lateral view: slender such that the proximal end of the bone widens abruptly from the shaft and the iliofibularis tubercle is a distinct emargination (0); only the posterior margin widens abruptly proximally and the tubercle is a subtle emargination (1); stout, such that the proximal end does not dilate abruptly from the shaft and the tubercle is a subtle emargination (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1), FMNH PR2081 (2).

1649. Fibula, bone, lateral surface, form, lateral view: the lateral surface is subtly convex in horizontal section but cannot be described a columnar (0), lateral surface of the bone is distinctly convex and columnar throughout its entire height (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1650. Fibula, proximal end, mediolateral width, proximal view: narrow (width to length ratio: equal to or less than 22%) relative to anteroposterior length (0), wide relative to length (ratio: 26%) (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1).

Note: This character can be quantified by taking the ratio of the mediolateral width of the proximal end at its midlength to the maximum rostrocaudal length of the proximal end of the bone. The narrow condition is seen in BMRP 2002.4.1 (30 mm, 139.2 mm) with a ratio of 22%, the wide condition is seen in LACM 23845 (43.8 mm, 165.7 mm) with a ratio of 26%.

1651. Fibula, proximal end, shape, proximal view: tapers (narrows) as it extends posteriorly (0); widens then tapers posteriorly, or nearly uniform in width, only a slight reduction from the anterior to the posterior end (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1652. Fibula, proximal end, medial margin, posterior half, form, proximal view: concave (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1653. Fibula, proximal end, anterior end, form, proximal view: subtly convex (0), tall mediolateral ridge (1), distinctly convex and almost knob-like (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1654. Fibula, proximal end, form, proximal view: joint surface is subtly convex in mediolateral section and is not bounded laterally by a low ridge (0), concave in cross section and bounded laterally by a low ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1655. Fibula, proximal end, posterior end, form, proximal view: relatively wide and tapers to a point (0); narrow, tapers, and extends posteromedially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1656. Fibula, medial joint surface for the tibia dorsal and anterior to the medial fossa, orientation, proximal view: oriented vertically and so it does not extend into view (0), oriented ventromedially and so extends into view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1657. Fibula, proximal end of the bone, dorsal margin, form, lateral and medial views: subtly concave, nearly straight (0); differentiation into distinct anterior and posterior knob-like convexities that produces a deeply concave dorsal margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1658. Fibula, proximal end of bone, posterodorsal quadrant, fossa, presence, lateral view: deep fossa is present that is sharply delimited anteriorly by a sharp, vertical ridge, and the fossa abruptly shallows out far above the narrowest point of the proximal end of the shaft (0); the corresponding surface is shallowly concave and is not delimited anteriorly by a ridge, where it grades into the convex lateral surface of the bone, but ventrally this surface deepens into a fossa that extends down the shaft, fading out a short distance above the level of the tubercle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1659. Fibula, proximal end of the bone, form, lateral view: lateral surface is convex and

bulges a short distance below the proximal end, above this the lateral surface is concave and subtly flares dorsolaterally to the proximal surface (0); the entire proximal region above the iliofibularis tubercle flares dorsolaterally to the proximal joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1660. Fibula, proximal end of the bone, anterior margin, form, lateral view: concave since the medial flange is positioned posterior to the leading edge of the bone and extends directly medially (0), convex since the medial flange extends anteromedially into view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1661. Fibula, iliofibularis tubercle, lateral ridge, form, lateral view: a low ridge that is coarse and concave in vertical section (0), a prominent ridge that is only subtly concave in vertical section (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1662. Fibula, iliofibularis tubercle, position on shaft with bone lying flat on a table, lateral view: positioned along the anterolateral edge of the shaft, concealing much of the medial ridge from view and the lateral ridge is limited to the anterior edge of the bone (0); positioned on anterolateral surface, medial ridge is marginally in view, lateral ridge does not extend across lateral surface of shaft (1); positioned on the lateral surface of the shaft, where the medial ridge is exposed to view and the lateral ridge nearly extends across the lateral surface of the shaft (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

1663. Fibula, iliofibularis tubercle, lateral ridge, differentiation from shaft, anterior view: the dorsal end of the ridge grades into the anterolateral edge of the shaft, whereas its ventral end is sharply differentiated from the shaft (0); both dorsal and ventral ends of the shaft are sharply differentiated from the shaft (1); both ends grade into the shaft (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1), LACM 23844 (2).

1664. Fibula, anterior surface, distal end, form, anterior view: the medial edge of the shaft subtly widens ventrally (0); both the lateral and medial edges of the shaft dilate toward the distal end of the bone, and the medial edge flares widely (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1665. Fibula, flared distal end, form, anterior view: straight (0), abruptly deviates laterally (1).

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1).

1666. Fibula, distal end, condylar surface for the calcaneum, form, anterior and ventral views: the joint surface is subtly convex mediolaterally (0), the joint surface is trochlear and excavated by an anteroposteriorly extending groove (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1667. Fibula, distal end, distinction between the shaft and the ventral joint surface for the calcaneum, lateral view: the shaft flares subtly toward the ventral joint surface (0); the shaft

flares abruptly toward the ventral joint surface but a posteroventrally extending crease is not produced at the ventral end of the shaft (1); the shaft flares abruptly toward the ventral joint surface such that a deep, posteroventrally extending crease is produced at the ventral end of the shaft (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1668. Fibula, distal end, anterior margin, form, lateral view: the leading edge is not interrupted at the ventral joint surface for the calcaneum (0), the region of the ventral joint surface bulges anteriorly and emarginates the leading edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1669. Fibula, proximal region above the iliofibularis tubercle, form, anterior view: mediolaterally narrow despite the medially-extending flange (0); mediolaterally wide and hatchet-like, where the medial flange extends strongly ventromedially from the proximal end of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1670. Fibula, proximal region above the iliofibularis tubercle, medial flange, muscle scar, form, anterior view: scar is a deep, vertical cleft in the anteromedial edge of the flange (0); scar is a shallow, wide, and coarse concavity in the anteromedial surface of the flange (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1671. Fibula, proximal region above the iliofibularis tubercle, medial surface, muscle scar between the medial fossa (above) and the tubercle (below), form, anterior view: low ridge that is marginally seen in anterior view (0), a prominent and coarse ridge that is seen in anterior view (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1672. Fibula, anterior surface immediately proximal to the iliofibularis tubercle, anterior view: a narrow ridge that extends dorsomedially to the medial flange (0), narrow ridge that extends dorsally (1), a wide flat surface that gradually tapers as it extends dorsally or dorsomedially toward the base of the medial flange (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1), FMNH PR2081 (2).

1673. Fibula, proximal region above the iliofibularis tubercle, medial surface, medial flange, anteroposterior position, medial view: positioned posteriorly, behind the anterolateral leading edge of the bone (0); extends along and forms the anterior margin of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1674. Fibula, medial fossa, dorsal margin, orientation, medial view: extends nearly horizontally (subtly anteroventrally) (0), extends distinctly anteroventrally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1675. Fibula, medial fossa, differentiation into a pair of subordinate fossae, medial view: subtle differentiation where the deep anterior fossa grades into the shallow posterior fossa (0),

sharply differentiated where the anterior fossa is larger and more deeply excavated than the shallower posterior fossa that is bounded posteriorly by a distinct ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1676. Fibula, medial joint surface for the tibia above the medial fossa, texture: subtly coarsened by steeply anteroventrally trending ridges and grooves (0); coarsely textured by high-relief, steeply anteroventrally trending ridges and grooves (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1677. Fibula, medial fossa, anterior subfossa, loci of deepest excavations, medial view: the anterodorsal corner is most deeply excavated and the fossa grades ventrally into the medial surface of the shaft (0); the anterodorsal, posterodorsal, and ventral corners are the most deeply excavated parts of the fossa, the fossa is starkly differentiated from the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1678. Fibula, proximal end, posterodorsal form, medial view: convex (0), angular (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1679. Fibula, medial fossa, posterior extent, medial view: the medial fossa extends along the posterior margin of the bone (0), a wide ridge separates the fossa from the posterior edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1680. Fibula, proximal end of bone, posterior ridge, presence, medial view: a subtle ridge extends along the posteromedial margin of the bone that fades ventrally above the level of the iliofibularis tubercle (0); a massive ridge that extends dorsally from below the level of the tubercle and extends nearly to the posterodorsal corner of the bone, fading behind the posterior subordinate fossa (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1681. Fibula, ventral half of shaft below the iliofibularis tubercle, scar and joint surface that excavates the posteromedial edge of the shaft, form, medial view: distinct and deeply carves out the posteromedial surface of the bone, and has a distinct dorsal end that is sharply differentiated from the medial surface of the shaft (0); the scar is distinct ventrally as a narrow ridge that dorsally widens and fades into the posteromedial edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1682. Fibula, ventral end, region that flares anteroposteriorly, form, medial view: region subtly flares anteroposteriorly, the joint surface is generally flat with a subtle vertical ridge, and the surface is bounded posteriorly by a ridge (0); the region subtly flares anteroposteriorly, the joint surface is shallowly concave in anteroposterior section, and it is bounded anteriorly by a narrow ridge and posteriorly by a thick ridge (1); the region distinctly flares anteroposteriorly, the joint surface is deeply concave in anteroposterior section, and it is bounded anteriorly by a narrow ridge and posteriorly by a thick ridge (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1683. Fibula, ventral end below the level of the iliofibularis tubercle, form, medial view: deeply concave and groove-like from the level of the midheight of the tubercle ventrally to the proximal end of the dilated distal (=ventral) region (0), shallowly concave (1), columnar and convex from the level of the tubercle ventrally before stopping at the concave dilated region, low vertical ridges that extend along the anteromedial and posteromedial edge of the bone bound the columnar region in front and behind (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

1684. Fibula, proximal end of bone above the level of the iliofibularis tubercle, posterior edge, form, posterior view: thin, blade-like edge (0), narrow blunt-edged ridge (1), wide blunt-edged ridge (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 1125 (1), FMNH PR2081 (2).

1685. Fibula, proximal end, lateral surface, muscle scar and ‘shelf’, presence, lateral view: an extensive muscle scar excavates the lateral surface of the bone that is delimited along its posterior half by a very narrow, shelf-like ridge (0); the scar is vanishingly subtle and its delimited by a series of subtle, vertically-oriented ridges and grooves (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1686. Fibula, surface distal to the bipartite scar, mediolateral width, anterior view: wide and flat (0), narrow (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1687. Fibula, proximal region, anterior margin, orientation, lateral view: extends anterodorsally toward the proximal joint surface (i.e., dilation present) (0), subtle dilation is present and then extends vertically to the proximal joint surface (1), extends vertically to the joint surface (i.e., dilation absent) (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 009 (1), FMNH PR2081 (2).

1688. Fibula, proximal region, anterior margin immediately below anterodorsal corner, bulge-like tubercle, presence, lateral view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

PES

METATARSAL II (8 characters)

1689. MTT II, circumference to length ratio: 34% (0), equal to or greater than 42% (1).

Exemplars: BMRP 2002.4.1 (0), LACM 23845 (1).

1690. MTT II, ratio of distal length to distal width: 92%, wider than long (0); 99%, as wide as long or longer than wide (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1691. MTT II, shaft, proximal half, anterolateral edge, spur, presence, anterior view: a spur is absent, only a low swelling is seen (0); distinct, dorsally-extending spur is present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1692. MTT II, tubercle above lateral half of distal condyle, anterior view: low bump (0), distinct tubercle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1693. MTT II, distal condyle, form, distal view: shallowly dissected by branching sulci (0); deeply dissected by numerous branching sulci, including the lateral edge of the condyle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1694. MTT II, proximal end, lateral margin that abuts mtt IV, orientation, proximal view: parasagittal (0), anterolateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1695. MTT II, medial collateral ligament pit, form, medial view: shallow with a distinct and undercut ventral edge (0), deep pit (1), infilled with coarse bone (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), CM 9380 (1), FMNH PR2081 (2).

1696. MTT II, posteromedial scar, width, posterior view: narrow (0), greater than half the width of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

Note: This scar marks the insertion of the lateral part of the gastrocnemial muscle (Carrano and Hutchinson, 2002).

DIGIT II, PHALANX 1

1697. DII, PH1, lateral ventrolateral condyle, exposure, dorsal view: extends widely into view (0), narrowly exposed in dorsal view (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1698. DII, PH1, proximomedial insertion scar, tubercle, presence, ventral view: tubercle is absent, the scar is concave and coarse (0); large, burr-like scar occupies the dorsal half of the scar (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1699. DII, PH1, lateral ridge of flexor groove, form, ventral view: extends at a low posterolateral angle (more posterior than lateral) (0); flares distinctly laterally, abruptly widening the posterior end of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1700. DII, PH1, distal condyles, proportions, distal view: narrow, ratio of the height to width is 84% or more (0); wide, ratio of the height to width is less than 84% (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1701. DII, PH1, relative height of distal condyles, distal view: lateral condyle is taller than the medial condyle (0), condyles are of equal height (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1702. DII, PH1, notch between proximoplantar ridges, mediolateral width, posterior view: wide (0), narrow (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1703. DII, PH1, proximal joint surface, angulation in the medial margin, dorsoventral position, posterior view: at midheight of the joint surface (0), below midheight of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1704. DII, PH1, proximal joint surface, apex, mediolateral position, posterior view: lateral, centered over the lateral flexor ridge (0); medial, centered over the notch between the ridges (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1705. DII, PH1, lateral collateral ligament pit, orientation, lateral view: anteroventral (0), horizontal to subtly anterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

DIGIT II, PHALANX 2 (20 characters)

1706. DII, PH2, bone, form, dorsal view: long and slender (0), stout (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1707. DII, PH2, proximal joint surface, ventral margin, form, posterior view: subtly convex between subtle lateral and medial ventral extensions (0), subtly dorsally concave (1), dorsally concave between distinct ventrolateral and ventromedial corners of the joint surface (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), FMNH PR2081 (2).

1708. DII, PH2, proximal joint surface, texture, posterior view: smooth (0), pocked (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1709. DII, PH2, region of supracondylar pit, texture, dorsal view: pit is subtly defined and the surface is lightly coarse (0), posterior margin of the pit is relatively distinctly defined and the entire region is rugose (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1710. DII, PH2, shaft, lateral and medial margins, form, dorsal view: lateral margin is subtly concave, medial margin is subtly convex (0); lateral margin is distinctly concave, medial margin is subtly convex (1); lateral margin is distinctly concave, medial margin is distinctly convex (2).

ORDERED

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1711. DII, PH2, lateral distal condyle, orientation, lateral view: entire margin is convex (0), anterodorsal margin is flattened such that the condyle appears to face more directly anteriorly (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1712. DII, PH2, medial distal condyle, elevation relative to dorsum of bone, medial view: level with dorsum (0), extends subtly anterodorsally (1), extends abruptly anterodorsally relative to dorsum (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), FMNH PR2081 (2).

1713. DII, PH2, ventral condyles, orientation relative to venter of bone, lateral and medial views: low anteroventral angle (0), steep or abrupt anteroventral angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1714. DII, PH2, proximodorsal flange that extends over the proximal joint surface, width, dorsal view: narrow and tab-like (0), mediolaterally wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1715. DII, PH2, medial distal condyle, medial margin, orientation, ventral view: anteroposterior (0), anterolateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1716. DII, PH2, distal condyles, posterior margin, elevation relative to venter, ventral view: joint surfaces are level with the venter (0), joint surfaces are sharply elevated relative to the venter (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1717. DII, PH2, flexor groove, relative depth, ventral view: shallow with an indistinct anterior margin (0), deep with a distinctly inset anteromedial margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1718. DII, PH 2, distal condyles, orientation, lateral and medial views: low angle (0), distinct and steep (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1719. DII, PH2, medial distal condyle, ventral extent, posterior end relative to medial collateral ligament pit, medial view: stops below the midlength of the pit (0), stops close to the posterior margin of the pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1720. DII, PH2, collateral ligament pits, proximity to distal end of bone, lateral and medial views: do not closely approach the distal end (0), closely approach the distal end (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1721. DII, PH2, medial collateral ligament pit, long axis, orientation, medial view: horizontal (0), anterodorsal (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1722. DII, PH 2, collateral ligament pits, form, lateral and medial views: deep concave fossae (0), fossae are obscured by infilling of bone in their dorsal halves (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1723. DII, PH2, ridges above collateral ligament pits, texture, lateral and medial views: lightly coarse (0), rugose with papillae at their posterior ends (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1724. DII, PH2, distal condylar region of bone, orientation, dorsal view: extends subtly anterolaterally (0), extends distinctly anteromedially (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1725. DII, PH2, medial distal condyle, form, anterior view: narrow, subtly convex and tapers dorsomedially (0); wide, bulbous, and anterodorsally (more anterior than dorsal) facing (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1726. DII, PH2, lateral ridge above collateral ligament pit, form, dorsal and lateral views: ridge is not flange-like (0), posterior end extends laterally as a wide flange with a knob-like posterior extremity (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

METATARSAL III (8 characters)

1727. MTT III, distal condyle, form, distal view: not dissected by sulci (0), dissected by short sulci that extend anteriorly from its posterior margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1728. MTT III, proximal third of shaft, contact with MTT IV, anterior view (Parks, 1928): contact below the ankle joint (0), separate below the ankle joint (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1729. MTT III, proximal joint surface, shape, proximal view: “lightning bolt”, of three changes in direction (0); open V (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1730. MTT III, dorsolateral condyle, elevation, lateral view: level with anterior surface of shaft (0), sharply elevated by the deep supracondylar groove (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1731. MTT III, dorsomedial condyle, elevation, medial view: elevated (0), separated from anterior surface by a deep groove (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1732. MTT III, supracondylar groove, form, anterior view: deep laterally, fades medially (0); deep groove laterally, shallow but distinct groove medially (1); extremely deep pit laterally, narrows to a deep groove medially (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1733. MTT III, distal condyle, distal margin, form, anterior view: indented (0), convex (1).

Exemplars: DDM 1536.8 (0), BMRP 2002.4.1 (1).

1734. MTT III, proximal joint surface for MTT II, anterolaterally-facing surface, form, anterolateral view: knot-like scar is absent (0); marked toward its ventral margin by a distinct, large, knot-like scar surrounded by a low, U-shaped ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1735. MTT III, posterior ridge, orientation and position relative to lateral edge of shaft, posterior view: straight and gradually extends toward the lateral edge of the bone (0), reaches lateral edge of bone abruptly (distally) in region of medial flange from a distinct inflection point in the ridge (1).

Exemplars: DDM 1536.8 (0), DDM 35.131 (1).

1736. MTT III, platform above condyles, form, posterior view: a deeply concave, vertical channel between the condyles (0); shallow groove between the condyles (1), surface is flat (2).

ORDERED

Exemplars: DDM 1536.8 (0), DDM 35.131 (1), LACM 150167 (2).

1737. MTT III, oval scar at ventrolateral end of posterior ridge, form, posterior view: vanishingly shallow with a distinct medial margin (0); present as a distinct, coarse, and oval scar (1).

Exemplars: DDM 1536.8 (0), BMRP 2002.4.1 (1).

1738. MTT III, posterior ridge, ventral end, extent, posterior view: fades before reaching the platform of the condylar region and the shaft is wide between the ridge and condylar region (0); fades before reaching the platform of the condylar region and the shaft is narrow (pinched) between the ridge and condylar region (1); reaches the platform of the condylar region, and the shaft is narrow where the structures join, giving it a pinched appearance (2).

Exemplars: DDM 1536.8 (0), MOR 3028 (1), BMRP 2002.4.1 (2).

1739. MTT III, ridge that extends to each plantar condyle, form, posterior, lateral, and medial views: distinct and narrow (0), indistinct to absent (1).

Exemplars: DDM 1536.8 (0), BMRP 2002.4.1 (1).

1740. MTT III, condylar platform, form, posterior view: not a discrete, platform-like structure (0); a discrete, platform-like structure with a clearly defined dorsal edge (1).

Exemplars: DDM 1536.8 (0), FMNH PR2081 (1).

1741. MTT III, ridge that extends to each plantar condyle, external surface, form, posterior, lateral, and medial views: excavated by a groove (0), grooves absent (1).

Exemplars: DDM 1536.8 (0), BMRP 2002.4.1 (1).

1742. MTT III, distal condyle, form, distal view: asymmetrical, where the dorsomedial condyle extends distinctly dorsomedially, distinctly lengthening the condyle such that it is anteroposteriorly (=dorsoventrally) longer than mediolaterally wide (0); nearly symmetrical where the dorsomedial condyle does not extend greatly dorsalwards such that the condyle is mediolaterally wider than anteroposteriorly long (1).

Exemplars: DDM 1536.8 (0), BMRP 2002.4.1 (1).

1743. MTT III, medial distal condyle, orientation, medial view: extends at a continuous but relatively abrupt angle from the shaft (0); extends at a low, continuous angle from the shaft (1).

Exemplars: DDM 1536.8 (0), DDM 35.131 (1).

1744. MTT III, distal end of shaft, curvature, presence, lateral and medial views: entire distal end of bone curves in a plantarward direction (0), distal end is not curved where the anterior surface is flat but the posterior surface extends in a plantarward direction toward the distal condyles (1).

Exemplars: DDM 1536.8 (0), DDM 35.131 (1).

1745. MTT III, joint surface for metatarsal IV, form, lateral view: excavated by a vertical and distinct groove (0), groove is vanishingly shallow (1), groove is absent (2). **ORDERED**

Exemplars: DDM 1536.8 (0), DDM 35.131 (1), MOR 009 (2).

1746. MTT III, surface between the lateral collateral ligament pit and the joint surface for metatarsal IV, form, lateral view: smooth and concavo- (ventral half)-convex (dorsal half) (0); concave crossed by an anteroplantarly extending, coarse ridge (1).

Exemplars: DDM 1536.8 (0), DDM 35.131 (1).

1747. MTT III, distal end of the joint surface for metatarsal II, form, medial view: a wide and shallow groove situated toward the plantar surface of the bone (0); groove is absent, where the entire surface is flattened and subtly convex in anteroplantar section (1).

Exemplars: DDM 1536.8 (0), DDM 35.131 (1).

DIGIT III, PHALANX I (9 characters)

1748. DIII PHI, proximal joint surface, form, proximal view: smooth, concave surface (0); shallowly concave and deeply dissected by neurovascular grooves (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1749. DIII PHI, proximal joint surface, proportions, proximal view: wider than tall (0), taller than wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1750. DIII PHI, proximal region of shaft, dorsum, mediolateral cross section, dorsal view: subtly flattened (0), convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1751. DIII PHI, proximal region, ventral heel, form, ventral view: heel is distinct, deeply concave and bounded on each side by relatively distinct ridges (0); heel is indistinct, shallowly concave and bounded by indistinct or absent ridges (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1752. DIII PHI, proximal region, ventral heel, muscle scar, form, ventral view: the ventral muscle scar is indistinct, mottled, with an indistinct anterior boundary that separates it from the

nonscar surface (0); scar is distinct, coarsened by rostrocaudally trending striae, with a distinct and deeply inset anterior boundary that deeply sets it off from the nonscar surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1753. DIII PHI, supracondylar groove, form, dorsal view: the supracondylar groove that extends along the posterior edge of the distal condylar surface is a relatively shallow crease that extends across the dorsum of the bone and the posterior edge of the groove grades into the dorsum of the bone (0); the groove is deeply inset, and distinctly elevates each side of the distal condylar surface from the dorsum of the bone and its posterior edge is sharply inset relative to the dorsum of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1754. DIII PHI, lateral collateral ligament pit, form, lateral view: round in outline and shallowly excavated into the bone (0); lens-shaped in outline with a slight anterodorsal long axis and deeply inset into the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1755. DIII PHI, medial collateral ligament pit, form, medial view: elliptical with a rounded anterior margin (0), elliptical with a pointed anterior margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1756. DIII PHI, distal joint surface, anterior margin, form, dorsal view: concave (0), sinuous (i.e., concavoconvex) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DIGIT III, PHALANX 2 (12 characters)

1757. DIII PH2, overall form, dorsal and ventral views: bone is long and narrow (0), bone is rostrocaudally short and mediolaterally wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1758. DIII PH2, proximal joint surface, form, proximal view: joint surface is slightly wider than tall (0), joint surface is distinctly wider than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1759. DIII PH2, ventral margin, form, proximal view: distinctly trilobate (0); bilobate, where the lateral indentation is vanishingly shallow (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1760. DIII PH2, supracondylar groove, form, dorsal view: shallow mediolateral crease that grades into the distal condylar surface (0); deep mediolateral groove that is differentiated into a pair of subtle pits adjacent to the dorsomedial and dorsolateral edges of the bone, the distal joint surface is sharply differentiated from the groove, especially from the midline medially as a sharp, crest-like edge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1761. DIII, PH2, distal joint surface, anterior margin, form, dorsal view: distinctly concave (0); subtly concave, nearly straight (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1762. DIII, PH2, distal joint surface, posterior margin, dorsal view: narrow and deeply convex (0), wide and subtly convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1763. DIII, PH2, distal joint surface, dorsal condyles, elevation relative to dorsum of the bone, lateral and medial views: the condyles extend at a low anterodorsal angle from the dorsum (0), the condyles extend at an abrupt and steep angle from the dorsum (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1764. DIII, PH2, distal joint surface, ventral condyles, orientation relative to venter of the bone, lateral and medial views: low anteroventral angle (0), steep anteroventral angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1765. DIII, PH2, medial collateral ligament pit, depth and size, medial view: deep, small, circular, with distinct margins (0); shallow, large, elliptical, with weakly defined margins.

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1766. DIII, PH2, flexor muscle scar, form, ventral view: concave and flanked by distinct lateral and medial ridges (0); flat and coarse, which obscures the wide and indistinct flanking ridges, reducing them to low swellings (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1767. DIII, PH2, distal condylar surface, posterior margin, orientation, ventral view: from anterolateral to posteromedial (0), from anteromedial to posterolateral (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1768. DIII, PH2, shaft, lateral and medial margins, form, ventral view: both margins are shallowly concave (0), lateral margin is deeply concave whereas the medial margin is shallowly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

METATARSAL IV (9 characters)

1769. MTT IV, circumference to length ratio: equal to or less than 29% (0), greater than 29% (e.g., 51%) (1).

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1).

1770. MTT IV, distal joint surface, form, distal view: anterolateral surface is dissected by branching sulci (0); posterior, anterolateral, and anteromedial surfaces are dissected by branching sulci (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1771. MTT IV, proximal surface, anterior and posterolateral margins, notches, depth, proximal view: subtle (0), distinct (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1772. MTT IV, medioventral heel, relative development, anterior view: a moderately developed and convex flange (0), massive but not triangular (1), a massively developed and triangular flange (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 009 (1), FMNH PR2081 (2).

1773. MTT IV, shaft, proximolateral edge, form, anterolateral view: narrow strut (0), columnar ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1774. MTT IV, shaft, anteromedial surface below proximal end, tuberosity, presence, anterior view (Parks, 1928): subtle (0), distinct and rugose (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1775. MTT IV, medial collateral ligament pit, depth, medial view: relatively deep and distinct (0), relatively shallow with an indistinct dorsal margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1776. MTT IV, groove that marks the lateral collateral pit, form, lateral view: groove (0); ventral half of the groove is occupied by a distinct, posteroventrally extending ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DIGIT IV, PHALANX 1 (17 characters)

1777. DIV, PH1, lateral collateral ligament pit, form, lateral view: vanishingly shallow, nearly level with lateral surface, bounded posteroventrally by a wrinkle-like ridge, and has an indistinct margin (0); relatively deep, distinctly inset relative to lateral surface, bounded posteroventrally by a distinct ridge, and has a relatively distinct margin (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1778. DIV, PH1, distal condyle, posterior edge, form, dorsal view: not crest-like throughout its entire extent (0), crest-like at lateral and medial condyles (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1779. DIV, PH1, supracondylar pit, form, dorsal view: a shallow crease that does not sharply offset the distal condyles (0), deep crease that sharply elevates the distal condyles from the dorsum of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1780. DIV, PH1, supracondylar pit, anteroposterior length, dorsal view: occupies one third of the shaft length (0), occupies less than one third of the shaft length (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1781. DIV, PH1, ventrolateral condyle, angle relative to shaft, lateral view: extends at a low anteroventral angle (more anterior than ventral) (0), extends at a steep anteroventral angle (more ventral than anterior) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1782. DIV, PH1, ventromedial condyle, angle relative to shaft, medial view: extends at a low anteroventral angle (0); extends at an abrupt and steep, anteroventral angle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1783. DIV, PH1, proximal joint surface, lateral half, form, posterior view: flat (0), nearly as deeply concave as the medial half of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1784. DIV, PH1, proximal joint surface, ventral notch, mediolateral position, posterior view: situated close to the lateral edge of the heel such that the lateral ridge is narrower than the medial ridge (0), situated at the midwidth such that the ridges are effectively equal in width (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1785. DIV, PH1, proximal joint surface, medioventral heel, posterior extent, dorsal view: extends posteriorly beyond the posterior margin of the proximal end of the bone (0), extends only marginally such that the posteroventral margin is nearly transversely oriented (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1786. DIV, PH1, distal joint surface, relative height of condyles, distal view: medial condyle is noticeably taller than the lateral condyle and the dorsal margin of the condylar surface is abruptly angled between them (0), medial condyle is subtly taller than the lateral condyle and the dorsal margin between them is smoothly concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1787. DIV, PH1, distal joint surface, width to height proportions, distal view: subtly wider than tall (0), significantly wider than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1788. DIV, PH1, lateral distal condyle, form, lateral view: anterior margin is strongly convex (0), anterior margin is flattened such that it extends subtly anterodorsally before curves posterodorsally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1789. DIV, PH1, lateral condyle, condylar surface relative to the lateral edge of the bone, dorsal view: extends subtly posteromedially away from the lateral edge (0), extends to the lateral edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1790. DIV, PH1, scar on shaft ahead of the proximal end of the bone, prominence, lateral view: low, coarse concave surface (0); coarse, convex, with a distinct anteroposterior ridge that extends across it (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1791. DIV, PH1, scar on shaft ahead of the proximal end of the bone, form, medial view: anteroventral corner is bounded by a low ridge (0), bounded by a massive and coarsely textured ridge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1792. DIV, PH1, shaft, dorsolateral surface, form, dorsal view: excavated by an anteroposteriorly extending groove (0), surface is convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1793. DIV, PH1, shaft, ridge lateral to the supracondylar pit, form, dorsal view: distinct and long, extends posteriorly past the midlength of the shaft (0); stout and fades along the supracondylar pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DIGIT IV, PHALANX 2 (12 characters)

1794. DIV, PH2, form, dorsal view: long and slender (0), short and wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1795. DIV, PH2, proximal joint surface, ventral margin, posterior view: each side of the ventral margin is flanked by a relatively distinct, ventrally extending process (0); only the lateral side of the ventral margin is flanked by a stout process (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1796. DIV, PH2, proximal joint surface, ratio of dorsoventral height to mediolateral width, proximal view: as tall as wide (0), wider than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1797. DIV, PH2, proximal joint surface, lateral margin, notch, presence, posterior view: absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1798. DIV, PH2, proximal joint surface, dorsomedial margin, form, posterior view: convex (0), concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1799. DIV, PH2, shaft, posterior half, form, lateral view: convex in dorsoventral section (0), occupied by a deep concave pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1800. DIV, PH2, ventral flexor muscle scar, form, ventral view: medial and lateral ridges are sharply defined (0), ridges are obscured by the swollen and coarse condition of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1801. DIV, PH2, shaft, dorsolateral surface, form, dorsal view: subtly convex in mediolateral section (0), distinct convex bulge (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1802. DIV, PH2, lateral collateral ligament pit, depth, lateral view: vanishingly shallow (0), deep and distinct pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1803. DIV, PH2, distal condyle, posterodorsal edge, form, dorsal view: subtly delimited from the dorsum of the bone (0), delimited from the dorsum by a sharp groove such that the condylar surface forms a narrow crest along the supracondylar pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1804. DIV, PH2, distal condyles, relative height, distal view: medial condyle is distinctly and significantly taller than the lateral condyle (0), medial condyle is a short distance taller than the lateral condyle (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1805. DIV, PH2, distal condyles, ratio of mediolateral width to dorsoventral height, distal view: slightly wider than tall such that the distal end is relatively narrow (0), greatly wider than tall such that the distal end is very wide (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DIGIT IV, PHALANX 3 (11 characters)

1806. DIV, PH3, form, dorsal view: distinctly longer than wide (long and slender) (0), marginally longer than wide (short and stout) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1807. DIV, PH3, dorsum, proximal scar, form, dorsal view: indistinct and convex (0), distinct and concave (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1808. DIV, PH3, dorsum, supracondylar pit, form, dorsal view: shallow and indistinct (0), deep and crease-like groove (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1809. DIV, PH3, ratio of mediolateral width to dorsoventral height, posterior view: marginally wider than tall (0), distinctly wider than tall (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1810. DIV, PH3, proximal joint surface, medial margin, form, posterior view: subtly convex (0), distinctly convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1811. DIV, PH3, lateral collateral ligament pit, depth, lateral view: shallow, nearly flush with lateral surface of the bone (0); deep pit (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1812. DIV, PH3, medial collateral ligament pit, depth and form: very deep, small, with sharp outline (0); deep, large, with indistinct outline (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1813. DIV, PH3, distal condylar region, ratio of width to height, distal view: distinctly wider than tall (equal to or less than height to width ratio of 61%) (0), extremely wider than tall (height to width ratio greater than 61%) (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1814. DIV, PH3, distal condyles, divergence, distal and dorsal views: diverge sharply from each other from a common point (0), separated by a shallow concave curve (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1815. DIV, PH3, shaft, flexor muscle scar, form, ventral view: broadly concave and flanked on each side by extremely coarse ridges (0), region is coarse and dominated by two coarse swellings that completely obscure the flanking ridges (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1816. DIV, PH3, distal condylar region, elevation below the ventral surface of the shaft, ventral view: subtly extend anteroventrally relative to the shaft (0), distinctly and abruptly extend anteroventrally from the shaft such that the structures are separated by a crease-like groove (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

DIGIT IV, PHALANX 4 (13 characters)

1817. DIV, PH4, dorsum, form, dorsal view: narrow and ridge-like (0), low and wide (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1818. DIV, PH4, dorsum, mediolateral orientation, dorsal view: extends at a very low ventrolateral angle, where the medial condyle is only subtly taller than the lateral condyle (0); extends at a distinct ventrolateral angle, where the medial condyle is distinctly taller than the lateral condyle (1); lateral condyle distinctly taller than medial condyle (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), LACM 23844 (2).

1819. DIV, PH4, proximal end of bone, width relative to distal end, dorsal view: same width (0), distinctly wider (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1820. DIV, PH4, distal joint surface, form, dorsal view: subtly concave, nearly roller-like (0); deeply and distinctly concave and separated into distinct lateral and medial condyles (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1821. DIV, PH4, flange that extends posteriorly over the proximal joint surface, form, dorsal view: narrow and relatively long (0), a subtle interruption along the posterodorsal margin of the bone (1), distinct and wide flange (2).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), LACM 23844 (2).

1822. DIV, PH4, proximal joint surface, form, posterior view: shallowly concave and separated into the lateral and medial halves by a subtle vertical ridge (0); vertical ridge is absent, and the entire joint surface is concave and deepened by a mediolaterally extending crease (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1823. DIV, PH4, proximal joint surface, posteroventral edge, posterodorsal view: subtly convex at the midline (0), distinctly convex and nearly pointed on the midline (1), distinctly dorsally concave (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1), LACM 150167 (2).

1824. DIV, PH4, distal joint surface, dorsal margin, indentation between condyles, presence, anterior view: absent, dorsal margin is level (0); present (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1825. DIV, PH4, medial distal condyle, form, ventral view: flat and faces more ventrally than anterolaterally (0); convex and bulbous, faces anterolaterally (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1826. DIV, PH4, distal condylar region, posterior margin, undercut, ventral view: level with the ventral surface, except along the medial condyle (0); entire posterior margin is undercut by a groove that separates it from the ventral surface of the shaft (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1827. DIV, PH4, distal condylar region, posterior margin, form, ventral view: deeply anteriorly concave, separating the lateral and medial condyles from each other (0); mediolaterally straight with no separation between condyles (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1828. DIV, PH4, lateral collateral ligament pit, form, lateral view: concave, large, and indistinct (0); vanishingly shallow (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

1829. DIV, PH4, medial collateral ligament pit, form, medial view: shallow, large, and indistinct (0); ventral region is excavated into a deep pit (1).

Exemplars: BMRP 2002.4.1 (0), BMRP 2006.4.4 (1).

PEDAL UNGUALS (3 characters)

1830. Pedal unguals, lateral collateral groove form, lateral view: groove is open laterally and not enclosed by a dorsally extending flange (0), tip of groove is closed (1), distal half of groove is enclosed by a flange that extends dorsally from the ventral margin of the groove (2), complete enclosure (3). **ORDERED**

Exemplars: BMRP 2007.4.1 (0), LACM 150167 (1), FMNH PR2081 (2), BMRP 2006.6.1 (3).

1831. Pedal unguals, medial ridge below collateral groove, form, medial view: ridge is not flattened and a distinct angulation is absent (0); distinctly flattened, concave, and smooth, producing a distinct angulation between the medial and ventral surface of the ungual (1).

Exemplars: BMRP 2006.4.4 (0), FMNH PR2081 (1).

Note: On the open side of BMRP 2006.4.4, there is a sharp angulation between the ridge and the ventral surface, but this is seen distally and the rest of the ridge is otherwise not flattened or concave.

1832. Pedal unguals, dorsum, foramina, dorsal view: foramina are absent (0); dorsum is pierced by numerous small, round foramina (1).

Exemplars: BMRP 2006.4.4 (0), FMNH PR2081 (1).

METATARSAL V (15 characters)

1833. MTT V, posterior rugosity, mediolateral width, posterior view: narrow, coarse ridge (0); wide, flat, coarse platform (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1834. MTT V, posterior rugosity, profile, medial view: the rugosity does not interrupt the posterior margin of the bone (0); the rugosity juts posteriorly, interrupting the posterior margin of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1835. MTT V, anterodorsal region along joint surface for metatarsal IV, form, medial view: anteroposteriorly narrow, not expanded anteriorly relative to the rest of the shaft (0); abruptly expanded anteriorly from the shaft, giving this region a hatchet-like appearance where a notch separates it from the dorsal extremity of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1836. MTT V, joint surface for metatarsal IV, exposure, medial and anterior views: limited to the medial surface of the bone (0); wraps onto the lateral surface of the bone at its anteroventral extent, forming a wide, coarse, and anteriorly facing joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1837. MTT V, lateral surface, orientation in horizontal section, lateral view: when lying flat on a table, the lateral surface trends at a low posteromedial angle throughout and the surface overall is flat (0); the lateral surface trends posterolaterally, especially along the ventral half of the bone and the surface overall is columnar and convex (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1838. MTT V, form, anterior view: the bone is mediolaterally narrow, only the anterior half of the proximal joint surface can be seen in anterior view, the flat ventral half faces anteriorly, the entire bone is dorsoventrally straight (0); the bone is mediolaterally wide, the entire proximal joint surface can be seen in anterior view, the proximal joint surface-bearing region extends

subtly dorsolaterally, the flattened anterior surface of the ventral half is greatly widened and extends slightly ventrolaterally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1839. MTT V, proximal joint surface, form, medial view: anteroposteriorly narrow and the ventral margin grades into the nonjoint surface (0), anteroposteriorly wide and the ventral margin is abruptly separated from the nonjoint surface by a series of coarse vertical ridges (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1840. MTT V, distal region, form, medial view: a shallow fossa separates the ridge-like anterolateral edge of the distal region from the coarse posterior scar (0); a deep fossa separates these structures, especially proximally (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1841. MTT V, posterior rugosity, dorsal extent, medial and posterior views: extends dorsally such that it extends past the level of the ventral margin of the medial joint surface (0), stops ventral to the level of the joint surface (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1842. MTT V, ventral tip, form, posteroventral view: bone tapers to a narrow, pointed, ventrolaterally extending point (0); tip is wide, but extends ventrolaterally (1); bone tapers to a wide, blunt, ventromedially extending point (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), LACM 150167 (1), FMNH PR2081 (2).

1843. MTT V, posterior rugosity, proximal end, position, posterior and lateral views: fades out on the posterior edge of the bone (0), fades out on the posteromedial surface of the bone (1), posterolateral (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1), MOR 980 (2).

1844. MTT V, proximal tip of the bone, form, dorsal view: mediolaterally narrow (0), intermediate (1), bulbous (2). **ORDERED**

Exemplars: BMRP 2002.4.1 (0), MOR 980 (1), FMNH PR2081 (2).

1845. MTT V, proximal joint surface, ventral end, form, anterior view: ventral end of the joint surface extends medially beyond the medial nonjoint surface of the bone (i.e., its ventral end is expanded medially) (0), ventral end of the joint surface is not expanded medially and grades ventrally into the shaft without interruption (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1846. MTT V, ventral half of bone, anteromedial edge, form, anterior view: proximal end of ridge formed by the anteromedial edge is prominent and juts medially relative to the shaft above it (0), the proximal end of the ridge does not jut medially and so it does not interrupt the medial edge of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1847. MTT V, posterior rugosity, papillae, location, posterior view: concentrated along the posteromedial edge of the bone (0), present on the posteromedial and posterolateral edges of the bone (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

GROWTH RINGS (2 characters)

1848. Growth rings, number (Erickson et al., 2004; Erickson, 2005): 2 (0), 3 (1), 12 (2), 13 (3), 14 (4), 15 (5), 16 (6), 18 (7), 22 (8), 28 (9). **ORDERED**

Exemplars: LACM 28471 (0), DDM 35.1 (1), BMRP 2002.4.1 (2), LACM 23845 (3), MOR 1125 (4), TMP 1981.012.0001 (5), FMNH PR2081 (6).

1849. External fundamental system (EFS), presence (Erickson et al., 2004): absent (0), present (1).

Exemplars: BMRP 2002.4.1 (0), FMNH PR2081 (1).

1850. Growth rate: moderate, longitudinal vascularity, poorly organized parallel fiber bundles in transverse section (0) (Woodward et al., 2020); active growing stopped, LAGs intervals less than 1 mm wide (1) (Horner and Padian, 2004).

1851. Ischium, posterior process, divergence, lateral view (Carpenter, 1990): steep angle (0), low angle (1).

Exemplars: TMP 1981.006.001 (0), AMNH FARB 5027 (1).

Figure 1. Skull of a small juvenile (CMNH 7541) *Tyrannosaurus rex* in left lateral view (quadratojugal, squamosal, and quadrate are restored after BRMP 2002.4.1) with a selection of ontogenetic characters and their states (in parentheses) labeled.

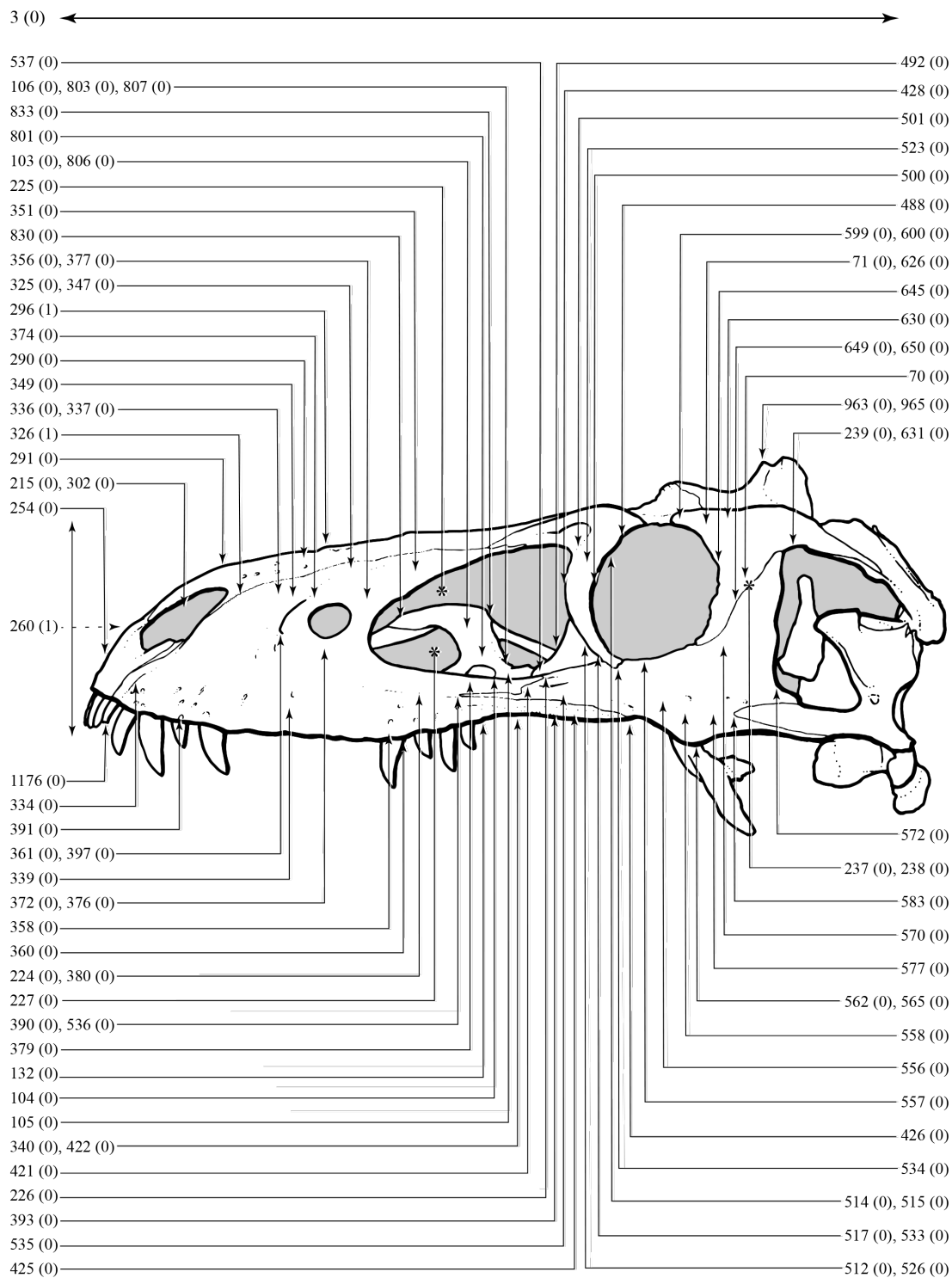


Figure 2. Skull of a large juvenile (BMRP 2002.4.1) *Tyrannosaurus rex* in left lateral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

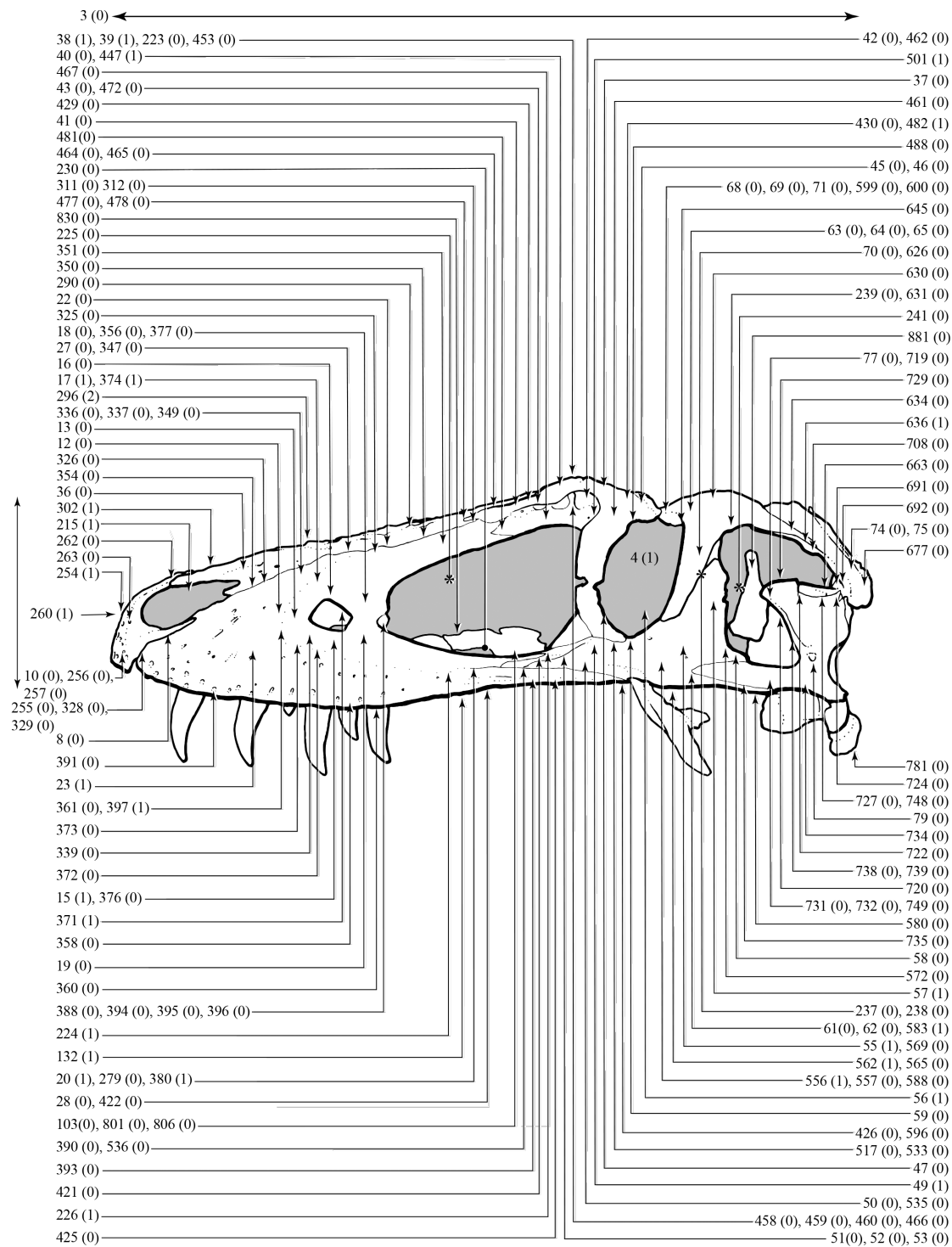


Figure 3. Skull of an adult (AMNH FARB 5027) *Tyrannosaurus rex* in left lateral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

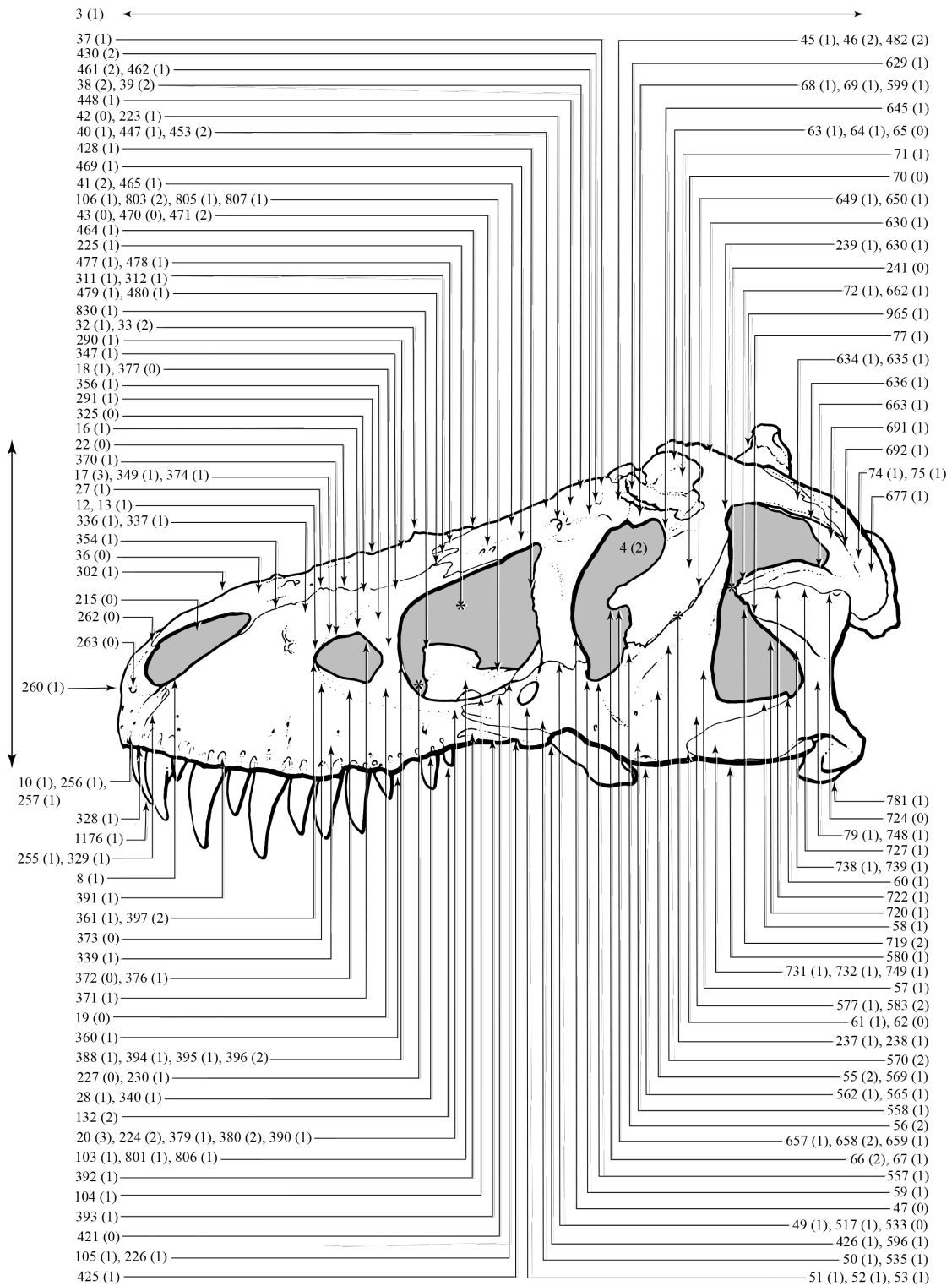


Figure 4. Skull of a small juvenile (CMNH 7541) *Tyrannosaurus rex* in dorsal view with a selection of ontogenetic characters and their states (in parentheses) labeled.

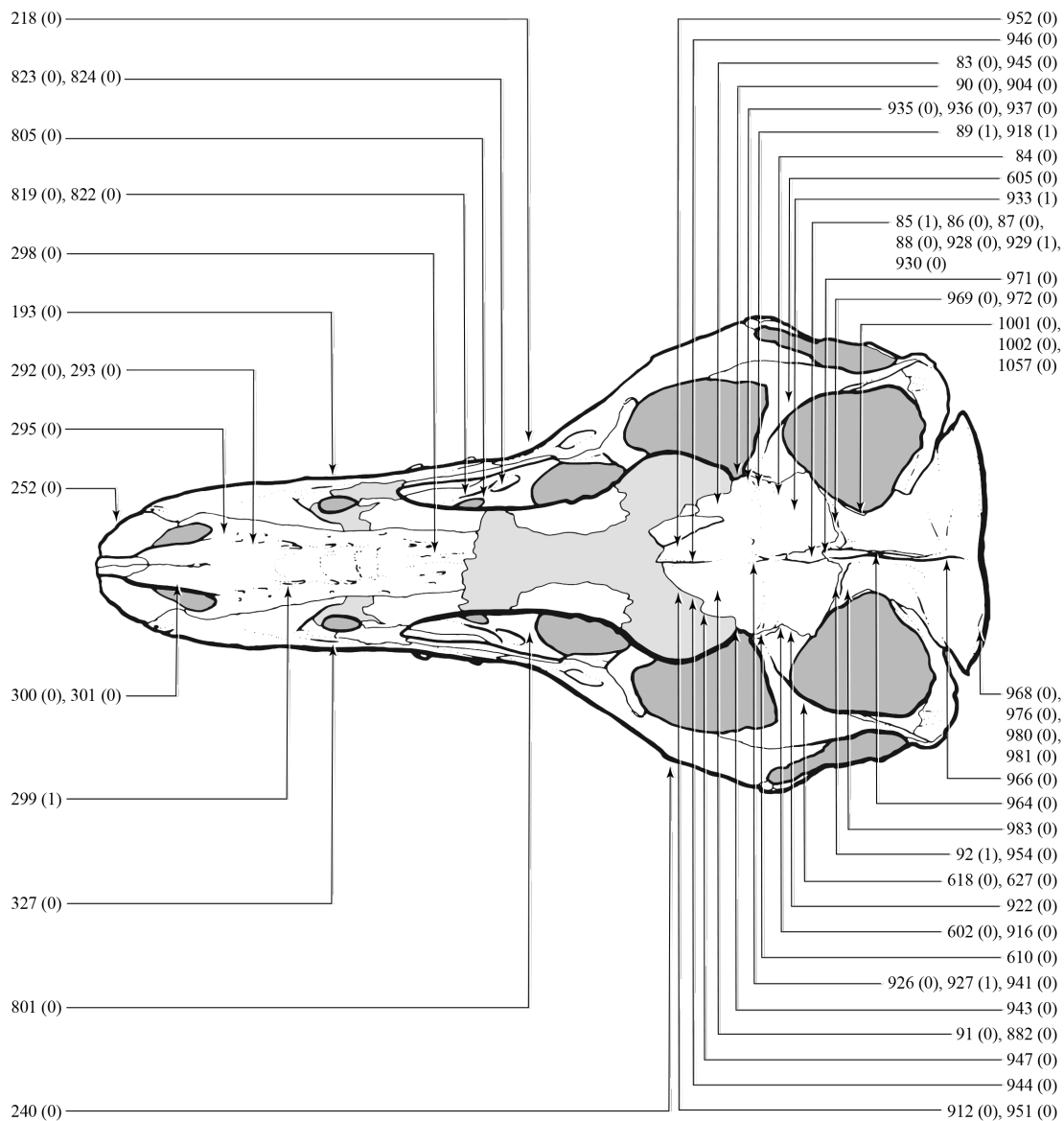


Figure 5. Skull of large juvenile (BMRP 2002.4.1) *Tyrannosaurus rex* in dorsal view with a selection of ontogenetic characters and their states (in parentheses) labeled.

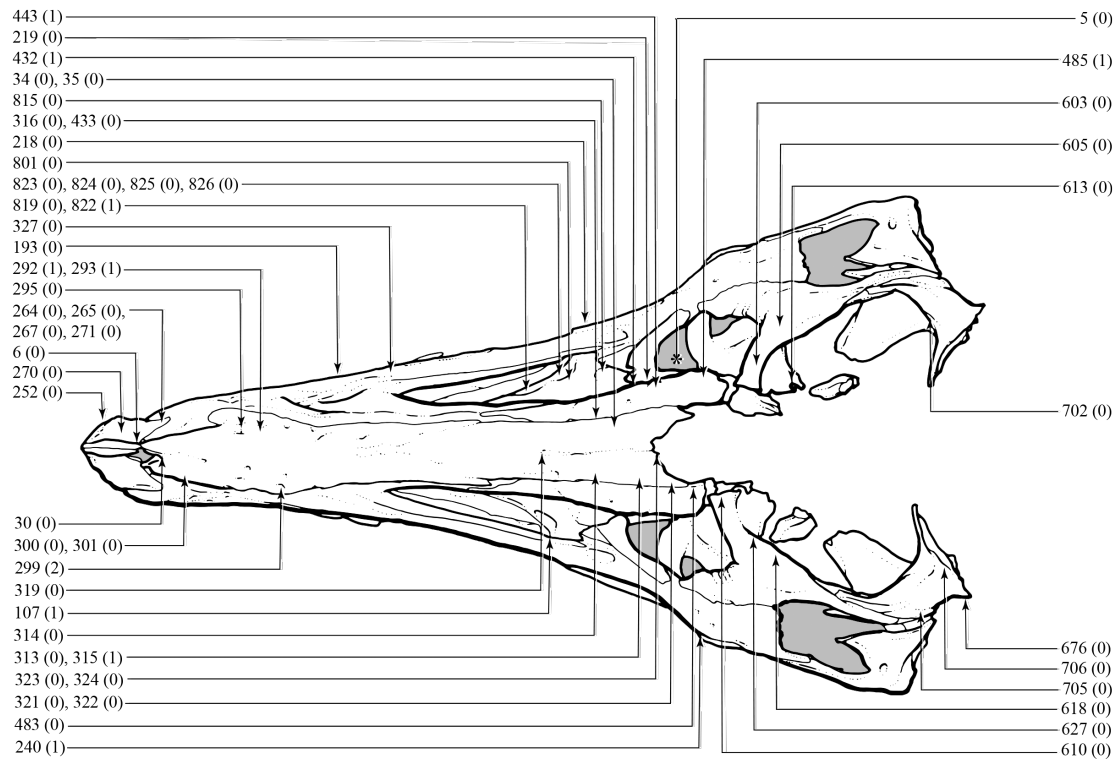


Figure 6. Skull of an adult (AMNH FARB 5027) *Tyrannosaurus rex* in dorsal view with a selection of ontogenetic characters and their states (in parentheses) labeled.

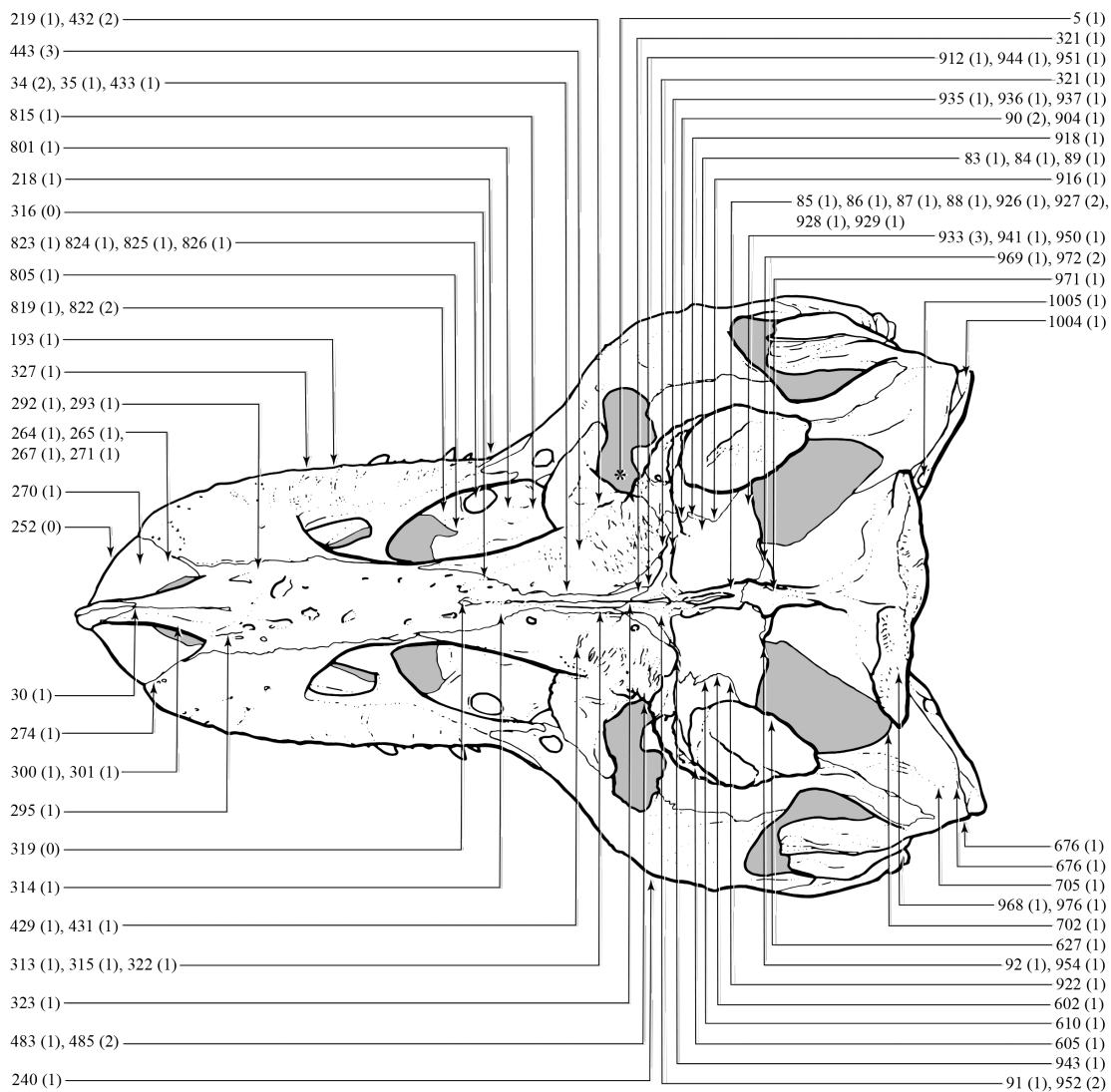


Figure 7. Skull of small juvenile (CMNH 7541) *Tyrannosaurus rex* in ventral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

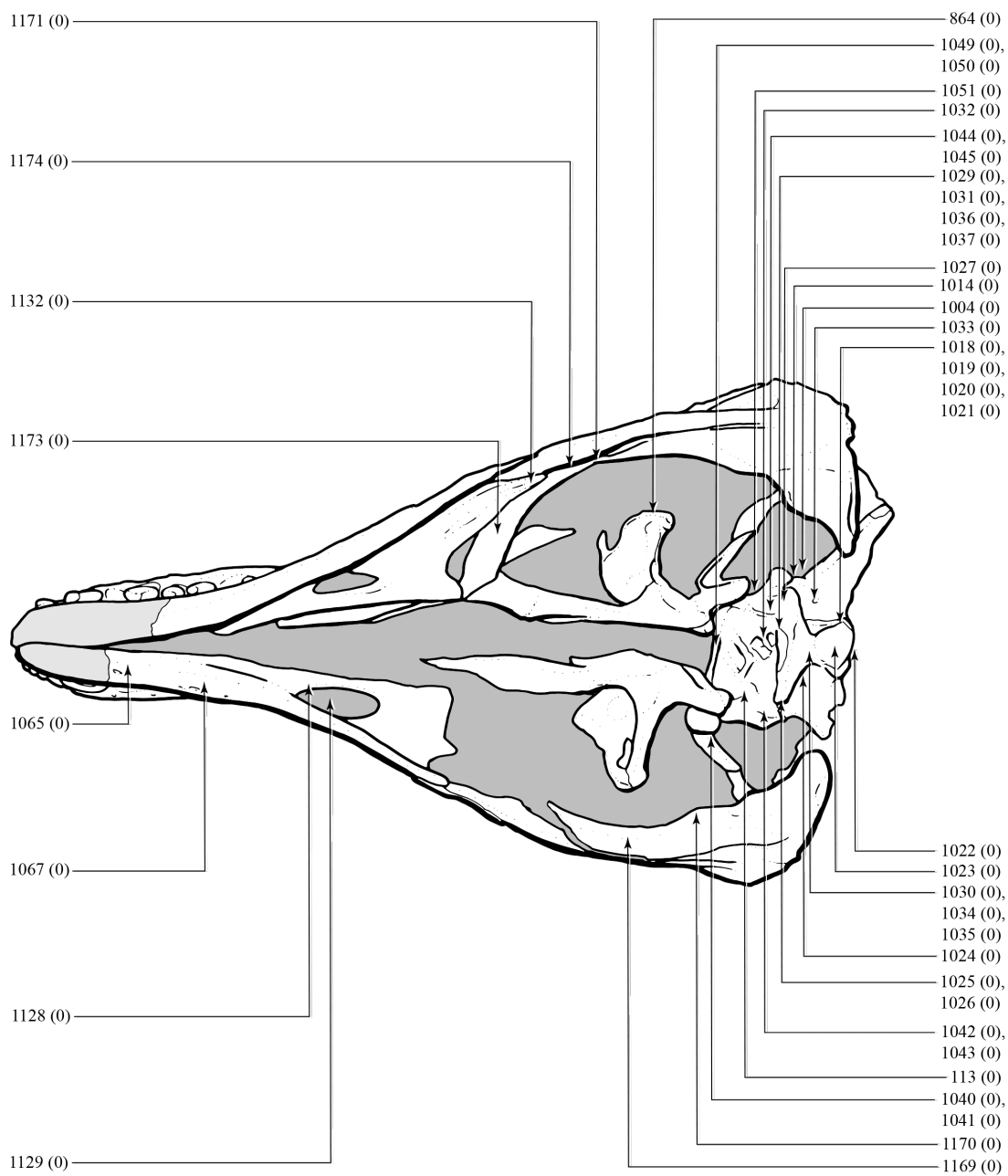


Figure 8. Skull of large juvenile (BMRP 2002.4.1) *Tyrannosaurus rex* in ventral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

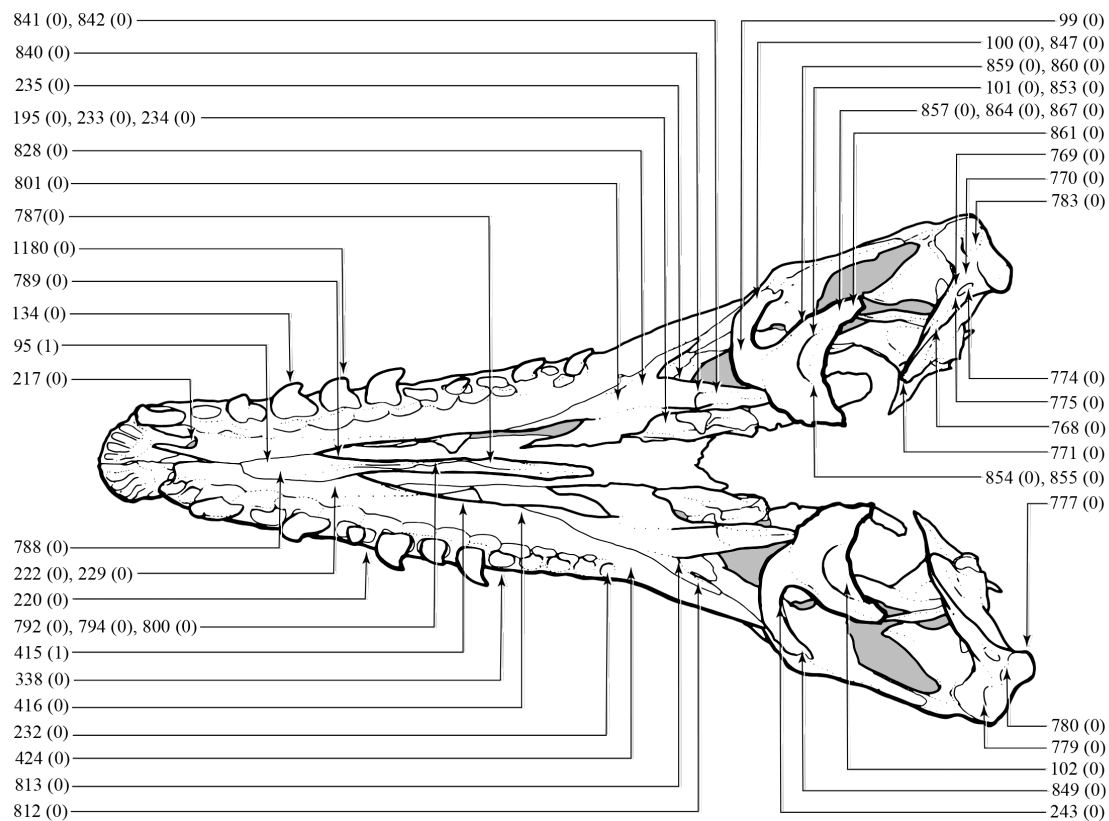


Figure 9. Skull of an adult (AMNH FARB 5027) *Tyrannosaurus rex* in ventral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

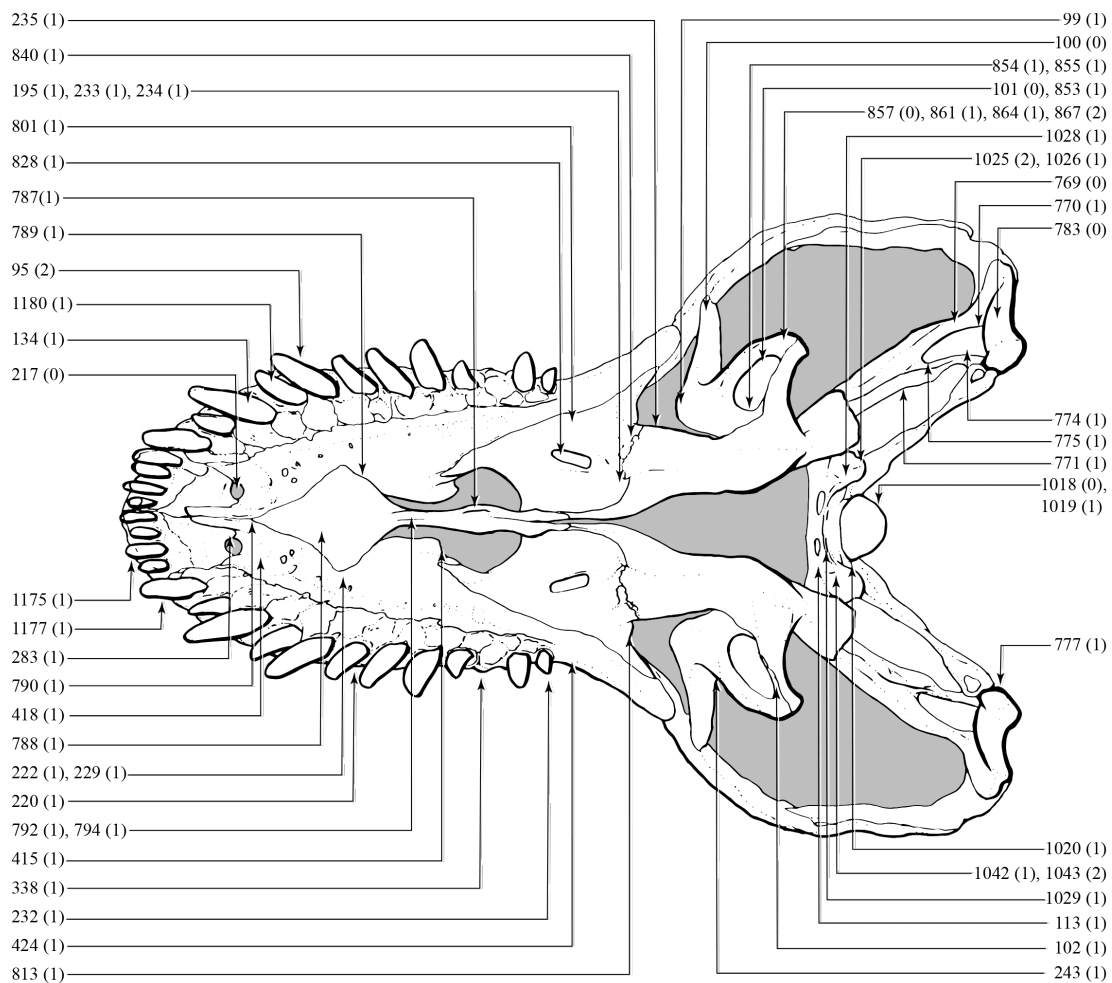


Figure 10. Mandibular ramus of a small juvenile (CMNH 7541) *Tyrannosaurus rex* in left lateral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

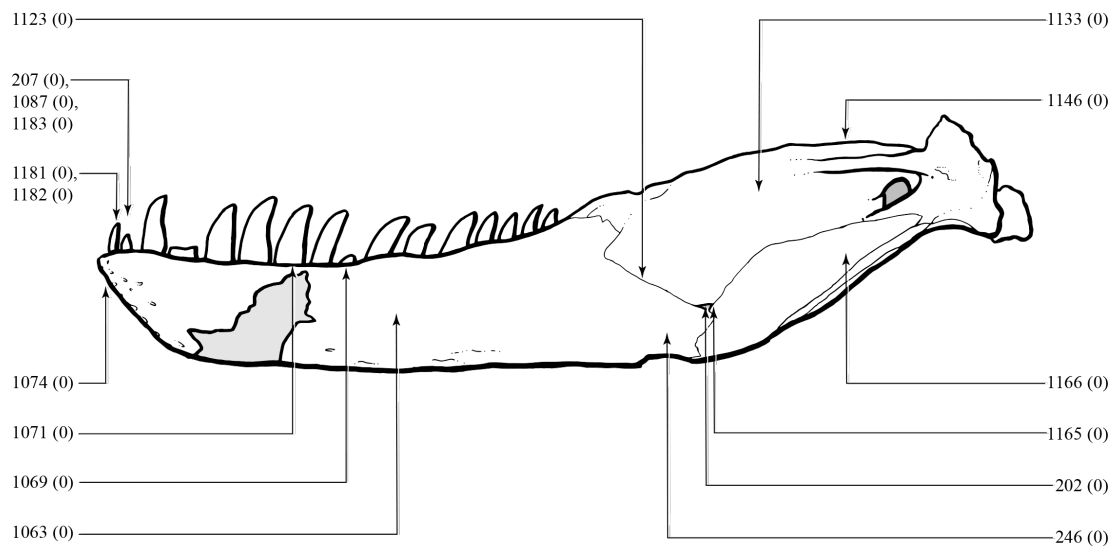


Figure 11. Mandibular ramus of a large juvenile (BMRP 2002.4.1) *Tyrannosaurus rex* in left lateral view with a selection of ontogenetic characters and their states (in parentheses) labeled.

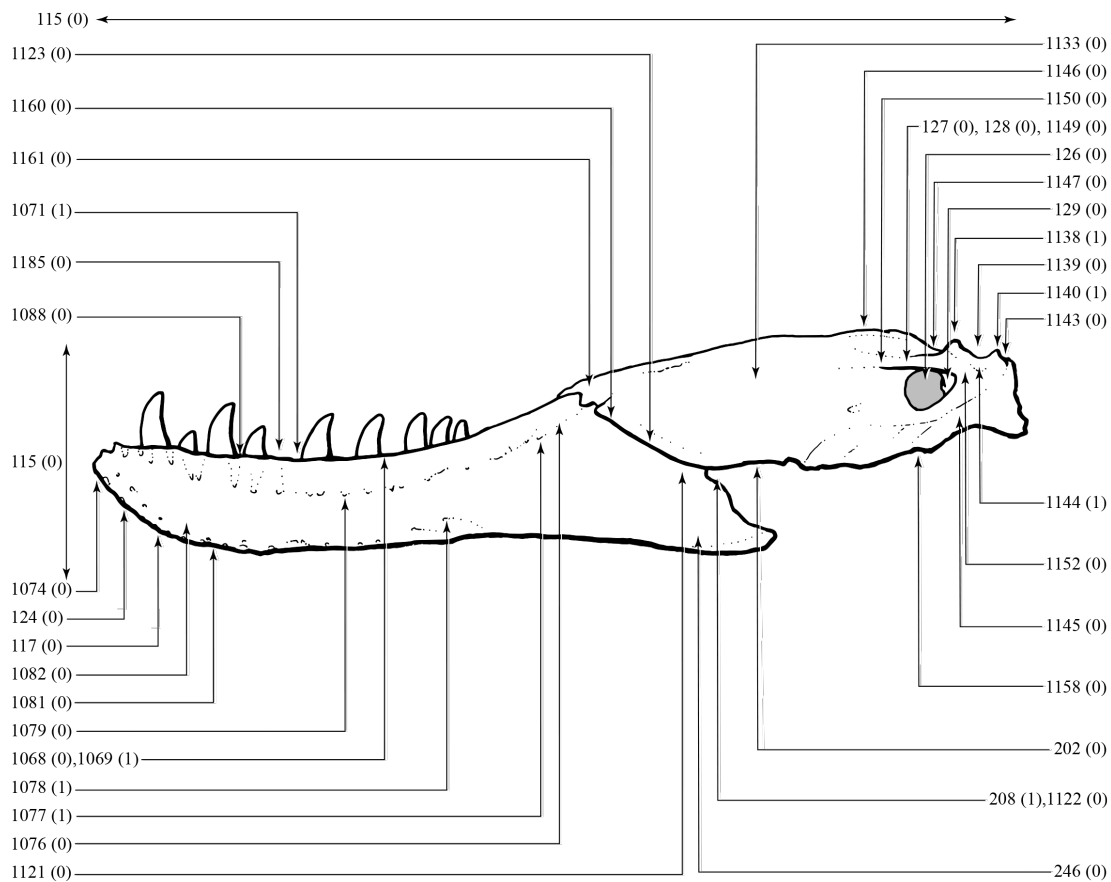
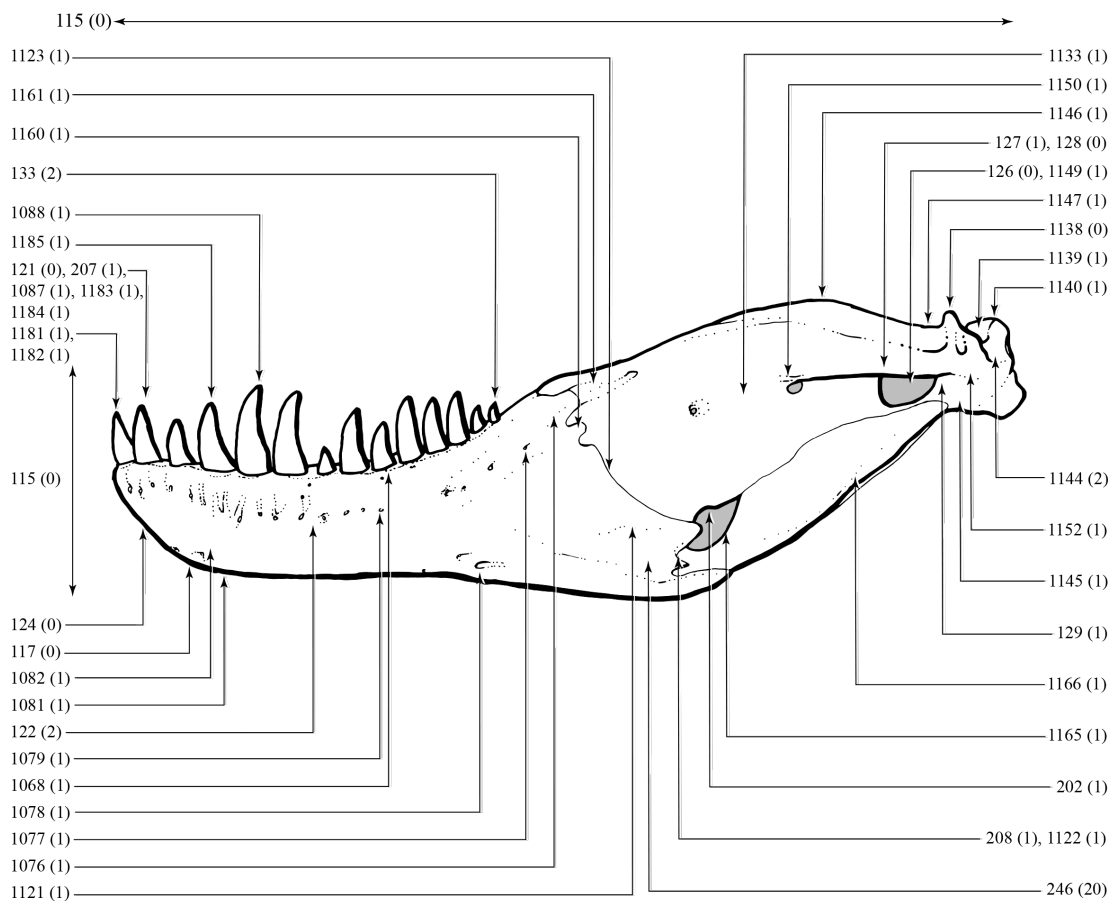


Figure 12. Mandibular ramus of an adult (AMNH FARB 5027) *Tyrannosaurus rex* in left lateral view with a selection of ontogenetic characters and their states (in parentheses) labeled.



Part B. List of ordered characters.

4, 20, 33, 34, 38, 39, 41, 46, 55, 56, 66, 81, 82, 85, 90, 93
107, 122, 132, 133, 138, 157, 198
210, 216, 224, 235, 248, 280, 296, 299
321, 351, 353, 356, 360, 374, 375, 380, 381, 396, 397
406, 407, 409, 410, 413, 415, 420, 427, 430, 431, 432, 440, 441, 443, 453, 459, 461, 464, 467,
471, 480, 482, 485, 486, 491, 492
504, 505, 523, 526, 530, 538, 546, 569, 570, 579, 583, 589, 590, 591
600, 608, 613, 618, 620, 622, 639, 640, 646, 658, 669, 698
701, 719, 728, 733, 735, 771
803, 811, 822, 838, 843, 858, 867, 885, 886, 892, 895, 898
900, 901, 903, 904, 910, 915, 916, 917, 920, 927, 931, 933, 937, 940, 942, 947, 949, 953, 968,
970, 972, 973, 983
1002, 1003, 1007, 1025, 1030, 1032, 1035, 1038, 1042, 1043, 1049, 1056, 1058, 1063, 1067,
1068, 1069, 1072, 1083, 1084, 1090, 1091, 1095
1100, 1122, 1130, 1131, 1134, 1137, 1144, 1164, 1166, 1179, 1184, 1189, 1193, 1195
1217, 1219, 1220, 1222, 1227, 1242, 1254, 1255
1307
1414, 1444, 1448, 1459
1624, 1625, 1629, 1633, 1634, 1648, 1653, 1662, 1663, 1667, 1672, 1682, 1683, 1684, 1695
1707, 1710, 1712, 1736
1818, 1823, 1830, 1842, 1843, 1844, 1848

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