Were the necks of *Apatosaurus* and *Brontosaurus* adapted for combat?

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The apatosaurine sauropods — *Apatosaurus*, *Brontosaurus* and possibly others — resemble their diplodocine relatives, but are generally more robust. Apatosaur necks are much thicker than in other sauropods: cervical ribs and their supports are uniquely robust, and the ribs are strongly displaced ventrally. The diapophyseal and parapophyseal rami therefore project ventrolaterally, so that the neck would have been subtriangular in cross-section, not tubular.

Why did apatosaurines evolve necks that were apomorphically expensive to build, maintain, and operate? While sexual selection is not a convincing explanation for the evolution of sauropod necks in general, several features of apatosaurine necks suggest adaptation for combat:

1. Ventral displacement of cervical ribs improved the lever arms of the hypaxial muscles, strengthening ventral neck movements.

2. Ventrolaterally directed parapophyseal rami were oriented to resist ventral impacts.

3. The ventral trough between the cervical ribs provided soft-tissue protection for the trachea, oesophagus, and major blood vessels.

4. The ventrolateral processes on the cervical ribs may have been bony clubs, bearing thickened pads of connective tissue or keratinous knobs or spikes.

These adaptations suggest a style of combat in which the neck itself was crashed down or sideways into the opponent, rather than giraffe-style combat in which the head is the weapon. The closest extant analogue may be the elephant seal *Mirounga*: males fight by crashing their necks and anterior thoraxes together. As with apatosaurs, their cervical vertebrae are more robust than in relatives, and their ventral processes more pronounced; but enormous soft-tissue padding makes the analogy very inexact.