Giant specimens of the sauropod dinosaur *Barosaurus* from Utah

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**Abstract**

The diplodocid sauropod *Barosaurus* is best known from the spectacular mounted skeleton in the atrium of the American Museum of Natural History (AMNH). Apart from the disproportionately long neck it is similar in size to *Diplodocus* — but did *Barosaurus* get bigger?

BYU field jacket 3GR was collected from the Jensen/Jensen quarry, Utah, in 1966 but only recently prepared. It contains three cervical vertebrae, designated A, B and C, anterior to posterior. They belong to *Barosaurus* based on elongation, broad prezygapophyseal facets, “hinged” prezygapophyseal rami with dorsomedial and dorsolateral faces, narrow, posteriorly set diapophyses bearing posterior tubercles, and wing-like postzygadiapophyseal laminae. Based on spine bifurcation, vertebra C is C9–C11. The centra of the AMNH cervicals C9–11 are 685, 737 and 775 mm long. That of vertebra C measures 1220 mm, making it 1.57–1.78 times longer. This suggests a neck length of 13.3–15.1 m based on the established length of 8.5 m for the AMNH specimen.

BYU 9024 is an even larger cervical vertebra, referred to *Supersaurus* but indistinguishable from C9 of *Barosaurus* based on the characters above. At 1370 mm in total length, it is exactly twice the length of the AMNH C9, suggesting a neck 17 m long.

**Keywords:** *Barosaurus*, *Supersaurus*, cervical vertebra, neck, size

Table of Contents

[Introduction 2](#__RefHeading___Toc4314_68767826)

[Historical background 2](#__RefHeading___Toc6557_68767826)

[Institutional Abbreviations 3](#__RefHeading___Toc3414_68767826)

[Anatomical abbreviations 3](#__RefHeading___Toc4320_68767826)

[Note on privately held material 3](#__RefHeading___Toc4815_68767826)

[Materials and Methods 4](#__RefHeading___Toc3397_68767826)

[Length of the neck of AMNH 6341 4](#__RefHeading___Toc6559_68767826)

[Method 1. Scaling from juvenile ?*Barosaurus* vertebrae 4](#__RefHeading___Toc6836_68767826)

[Method 2. Extrapolation from anterior *Diplodocus* vertebrae 5](#__RefHeading___Toc6838_68767826)

[Method 3. Extension by artistic intuition 6](#__RefHeading___Toc6840_68767826)

[Summary 6](#__RefHeading___Toc7244_68767826)

[Diagnostic characters of *Barosaurus* cervicals: 6](#__RefHeading___Toc6561_68767826)

[Results 7](#__RefHeading___Toc3399_68767826)

[*Barosaurus* compared with *Diplodocus* 8](#__RefHeading___Toc6842_68767826)

[Discussion 8](#__RefHeading___Toc3401_68767826)

[Acknowledgements 8](#__RefHeading___Toc3403_68767826)

[References 9](#__RefHeading___Toc3405_68767826)

[Figure Captions 10](#__RefHeading___Toc3407_68767826)

[Tables 11](#__RefHeading___Toc7266_68767826)

[Table A 11](#__RefHeading___Toc7275_68767826)

[Table B 11](#__RefHeading___Toc7268_68767826)

# Introduction

## Historical background

*Barosaurus* is a diplodocid sauropod from the Late Jurassic of North America, found in the extensive Morrison Formation. It was first described very briefly by Marsh (1890) in a six-page paper in which he also cursorily described the theropod *Ornithomimus* and two new species of *Triceratops*. The only *Barosaurus* elements mentioned in Marsh’s description were caudal vertebrae, and a single mid-caudal centrum was illustrated (Marsh 1890: figures 1–2). Marsh noted only that the caudals resembled those of *Diplodocus* but were proportionally shorter than in that genus and did not retain pneumatic features so far back along the tail.

The caudal vertebrae described by Marsh (1890) were part of a substantial partial specimen, YPM 492. More of this individual was subsequently excavated and prepared, and Lull (1911) wrote an important monographic description. This specimen includes numerous elements identified by Lull as four posterior cervicals (perhaps C12–15), six dorsal vertebrae (considered to be D1, 4, 5, 7, 9 and 10), a partial sacrum, about 19 caudal vertebrae from different parts of the tail, three chevrons, many ribs and fragments, the left sternal plate, a partial scapula, a partial ilium, partial right pubis, partial left ischium, femur fragments, tibia fragments and the ends of the left fibula. As is apparent, there is no skull and the appendicular material is fragmentary, so diagnosis rested primarily on the axial material. Lull (1919: plate II) illustrated three of the cervical vertebrae, but in monochrome and with only one of them shown in more than one aspect. Taylor and Wedel (2016: figures 3, 6–8) illustrated the same three cervicals in colour, each in four or five different aspects. (The fourth, designated Vertebra T, is too damaged to be informative.)

Since Lull’s monograph, *Barosaurus* has become better known from the more complete and better preserved specimen AMNH 6341. This was briefly described in McIntosh’s (2005) revision of the genus *Barosaurus* but has yet to receive a full monographic description. A cast based primarily on this specimen is mounted in a spectacular rearing posture in the Theodore Roosevelt Rotunda at the American Museum of Natural History (Figure B): see Taylor et al. (in prep) for detailed discussion of this mount.

More recently, a rediscovered specimen (ROM 3670) was mounted at the Royal Ontario Museum, having been overlooked in collections for decades. But it is largely uninformative as regards cervical morphology: signage in the public gallery indicates that only three cervicals — probably 12, 13 and 16 — are real fossil material, and they are all badly damaged. Garth Dallman (pers. comm., 2022) confirms that the missing vertebrae were filled in with casts from the Carnegie *Diplodocus* CM 84.

In the public gallery of the Natural History Museum of Utah, there is a *Barosaurus* mount in a crouching pose with a raised neck, based in part on real fossils. But the neck is cast from the ROM material (Randy Irmis and Garth Dallman, pers. comms., 2022), so it offers no new information on the cervical morphology. (The Utah *Barosaurus* mount has no single specimen number of its own, being a composite of many specimens.)

In conclusion, then, almost all understanding of the very distinctive neck of *Barosaurus* rests primarily on AMNH 6341, in which the last nine cervicals are preserved, and to a lesser degree on the holotype YPM 429.

## Institutional Abbreviations

* AMNH — American Museum of Natural History, New York, New York, USA.
* CM — Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.
* ROM — Royal Ontario Museum, Toronto, Canada.
* YPM — Yale Peabody Museum, New Haven, Connecticut, USA.

## Anatomical abbreviations

* PRDL — prezygadiapophyseal lamina
* PODL — postzygadiapophyseal lamina
* SPRL — spinoprezygapophyseal lamina

## Note on privately held material

XXX What to say about Western Paleo Labs?

# Materials and Methods

## Length of the neck of AMNH 6341

AMNH 6341 has the best-preserved neck of any *Barosaurus* specimen, but it suffers from two drawbacks.

First, the vertebrae are presently entombed under a glass walkway in a public gallery of the Museum, where they are effectively unavailable for scientific purposes. The walkway has become scuffed over time, becoming increasingly opaque, so that it is difficult to observe the vertebrae in dorsal view: the illustration in Taylor and Wedel (2016:figure 10) were obtained by shooting down through the translucent glass, and extensively manipulating the resulting photographs digitally, and even then the resolution is poor. Neither can the vertebrae be meaningfully observed in lateral view, as the walkways that runs above them is immediately behind a mounted skeleton of *Apatosaurus* and cannot be approached at ground level.

Second, only the last nine cervicals are preserved (along with the complete dorsal series). McIntosh (2005:45) considers these cervicals to be C8–C16: The number of cervicals is reckoned to be 16 on the basis that there are only nine dorsals, compared with ten in the closely related *Diplodocus*, and the most likely reason is that the first dorsal was recruited into the neck.) This assignment has been generally accepted, and will be followed here.

The sum of the total lengths of the nine preserved centra (from McIntosh 2005:table 2.1) is 6933 mm. However, since the anterior condyle of each vertebra will have been to come degree buried in the cotyle of its predecessor, it may be more appropriate to sum the “functional lengths” *sensu* Taylor and Wedel (2013:6): the length of the centrum omitting the anterior condyle. Happily, McIntosh (2005:table 2.1) includes this information, and the sum of these lengths is 6166 mm — 89% the length when summing the full centrum lengths. Which of these totals should be used? Evidence is equivocal. As shown by Taylor and Wedel (2013:table 4), the thickness of cartilage on cervical vertebrae relative to the bony centrum varies among sauropods from 4.5% for *Sauroposeidon* to about 20% for a juvenile *Apatosaurus*; and among a sample of extant animals, from 2.6% for the rhea to 24% for a juvenile giraffe. Even in *Sauroposeidon*, which has the least intervertebral cartilage of the sampled sauropods, the condyle of C6 barely penetrates the cotyle of C5 (Taylor and Wedel 2013:figures 11–12) and the condyle of C7 does not quite reach the cotyle lip of C6 (Taylor and Wedel 2013:figure 13). For this reason, we favour the use of total centrum lengths. However, we will make the following calculations on three bases: using total centrum lengths (6933 mm for C8–C16); using functional lengths (6166); and using a half-way compromise measurement (6550 mm).

How, then, can we determine the lengths of the seven missing anterior vertebrae? We will use three methods.

### Method 1. Scaling from juvenile ?*Barosaurus* vertebrae

There is no definite specimen of *Barosaurus lentus* that preserves the anterior cervicals. However, AMNH 7535 was included in Tschopp et al.’s (2015) specimen-level phylogenetic analysis of diplodocoids, and recovered as the outgroup to a clade containing (CM 11984 + (Barosaurus lentus holotype YPM 429 + AMNH 6341) (Tschopp et al. 2015:181). They therefore referred AMNH 7535 to *Barosaurus* sp. (Tschopp et al. 2015:220), and whether or not it actually belongs to *Barosaurus* it is probably the phylogenetically closest specimen that preserves the relevant vertebrae.

AMNH 7535 consists of skull fragments and cervicals 2–9. The atlas, C1, is missing, but it can be ignored here as its contribution to the length of the neck is negligible in sauropods. Interpretation of AMNH 7535 is hindered because it is much smaller than AMNH 6341 — either because it is a juvenile, or because it belongs to a dwarf species. There is some support for the latter interpretation because the neural synostoses are fully fused in all the vertebrae, so caution should be exercised when scaling from this individual.

With these caveats in mind, Table A shows the measurements of the eight preserved cervicals of AMNH 7535.

The last two vertebrae, C8 and C9, overlap with the two anteriormost vertebrae preserved in AMNH 6341. In the larger specimen, the centrum lengths are 618 and 685 mm, which are 1.97 and 1.89 times the length of the corresponding vertebrae in the smaller skeleton, for an average of 1.93 times the centrum length. Similarly, in AMNH 6341 the functional lengths of C8 and C9 are 590 and 630 mm, which are 2.02 and 1.93 times the functional length of the corresponding vertebrae in AMNH 7535, for an average of 1.98. We can therefore scale the total centrum length of AMNH 7535 C2–C7 up by a factor of 1.93 yielding a scaled total centrum length of 1903 mm; and scale the total functional length of AMNH 7535 C2–C7 up by a factor of 1.98, yielding a scaled total functional length of 1738 mm. The compromise value is intermediate between these, at 1821 mm.

This approach then yields a total estimated neck length of 7904 mm (if using functional lengths), 8371 mm (using compromise lengths) or 8836 mm (if using centrum lengths).

Wedel (2007:207) used a similar approach, scaling the AMNH 7535 vertebrae up to the size matching AMNH 6341, to arrive at his total neck length estimate of 8.5 m. Details of the method used in 2007 are now lost, so it is not apparent how the scaling constant was arrived at.

### Method 2. Extrapolation from anterior *Diplodocus* vertebrae

The neck of the CM 84, the holotype of *Diplodocus carnegii*, is the most complete, best preserved and most studied neck of any diplodocine sauropod, probably of any diplodocid, and possibly of any sauropod at all. Although the composition of the neck is not as firmly established as is often assumed, and the vertebrae are not as undamaged as they appear (Taylor 2022:8–11), the Carnegie *Diplodocus* neck remains as close to a “model organism” as we have, and can be used as a basis for scaling up anterior cervicals to fill in those missing from AMNH 6341.

Hatcher (1901:38) gives the total centrum lengths of the *Diplodocus* vertebrae, though not the functional lengths. The centra of the last nine vertebrae (C7–C15, corresponding to C8–C16 in *Barosaurus*) total 5224 mm, compared with 6933 mm for AMNH 6341: we can therefore say that the *Barosaurus* centra are on average 1.33 times as long as those of *Diplodocus*. The centra of C2–C7 in CM 82 total 1996 mm. (Note that we include C7 in both the posterior and anterior neck segments, since *Diplodocus* had one cervical fewer than *Barosaurus*.) If the C2–C7 were similarly 1.33 times as long in *Barosaurus*, they would have totalled 2655 mm, yielding a total neck length of 9588 mm.

Although Hatcher did not record the functional lengths of the CM 82 cervicals, we can still use the specimen to estimate a functional-length total for AMNH 6341 as follows. The total functional length of centra C8–16 in *Barosaurus* is 6166 mm, 1.18 times the total of full centrum lengths (5224 mm) in *Diplodocus*. We can therefore estimate that the total functional length of centra C2–C7 in Barosaurus is 1.18 times the total of centrum lengths (1996) in *Diplodocus*. This gives us a functional-length of 2356 mm for the missing segment of the *Barosaurus* neck, and therefore a total functional length of 8522 mm.

Finally, the compromise length for the C2–C7 segment using this method is the average of 2356 and 2655 mm, which is 2506 mm. Added to the compromise length for C8–C16 gives us a total neck length of 9056 mm.

### Method 3. Extension by artistic intuition

Scott Hartman’s skeletal reconstruction of *Barosaurus* (Figure A) is “Based on AMNH 6341, with additional information from CM 21774; missing cranial and distal caudal elements scaled from other diplodocids” (Hartman, pers. comm. 2022). CM 21774 consists of part of the right forelimb and manus (McIntosh 2005:61–63) so contributes nothing to the neck. Regarding the crucial first seven cervicals, Hartman writes “There wasn't any reference so I drew them falling off towards the anterior end […] Since the segmentation of sclerotome starts cranially (and the atlas and axis tend to be rather small, especially the former) there is inevitably going to be a ‘ramp up’ in length progressing towards longer, more posterior cervicals, but I admit that the exact rate of change in length progression itself doesn't have any hard and fast rules that I am aware of.” (Hartman, pers. comm. 2022). However, artistic intuition should not be discounted in such cases. Hartman has spent decades creating more than 30 skeletal reconstructions of sauropods and other dinosaurs, and has undoubtedly developed a feel for how their cervical sequences tend to be composed. Skeletal reconstructions by such experienced artists represent a synthesis of many observations and extrapolations.

In the reconstruction of Figure A, the sequence of C8–C16 (the vertebrae preserved in AMNH 6341) measures 1693 pixels, while the C1–C7 sequence measures 588 pixels — 34.7% of the lengths of the preserved sequence. Based on the candidate lengths 6166, 6550 and 6933 for C8–C16, this would mean C1–C7 is 2142, 2275 or 2408 mm, for a total neck length of 8307, 8825 or 9341 mm.

### Summary

Table B summarises the calculated total lengths of the neck of *Barosaurus lentus* AMNH 5341 based on the three candidate lengths of the C8–C16 sequence and the three estimation methods outlined above. Whether using the short, medium of long interpretations of the neck (i.e. condyles fully, partially or not at all nested within cotyles), scaling from *Diplodocus* gives the longest estimates and scaling from the referred juvenile *Barosaurus* sp. AMNH 7535 gives the shortest. The estimates vary from 7904 mm (short interpretation of scaling from AMNH 7535) to 9588 mm (long interpretation of scaling from *Diplodocus*), a difference of 1684 mm — a typical human height.

The average of the nine estimates made in this section is 8750 mm, and we will use this value as our best estimate.

## Diagnostic characters of *Barosaurus* cervicals:

* Elongation of centra
* Low, rounded neural spines
* XXX something about the slope from postzygs to top of cotyle?
* Forward sweep of CRL from diapophysis to paraphophysis
* Narrowness of CRL
* Thumb notch posterolateral to prezyg facet
* U-shaped notch between prezyg rami in dorsal view
* “Hinged” parapophyseal rami, angle between PRDL and SPRL
* Posteriorly directed process on diapophyseal process just above CRL
* Width of prezyg rami
* PRDL sweeps out to diapophysis
* Paired PCDLs radiating backwards and downwards from behind diapophysis

Diagnostic characters of cervicals in Revised Diagnosis of *Barosaurus* in Tschopp et al. (2015:261–262):

* (2) pleurocoel not extending onto parapophysis in anterior cervical vertebrae (158-1\*, unique among Diplodocidae)
* (3) elongation index of posterior cervical vertebrae (without anterior condyle) greater than 2.6 (192-2\*, unique among Diplodocoidea)
* (4) an anterior projection on the prdl of posterior cervical, or anterior and mid-dorsal vertebrae, right lateral to the prezygapophysis (213-1, unique among Diplodocoidea)

And of *Barosaurus lentus* (Tschopp at al. 2015:261–262):

* (1) cervical vertebrae pierced by a foramen on the dorsal side of the postzygodi- apophyseal lamina, just anterior to the base of the neural spine process (137-1, unique among Diplodocoidea, when assuming titanosauriform affinities of Australodocus)
* (2) EI (cervical centrum length, excluding condyle, divided by posterior centrum height) of posterior cervical vertebrae is higher than 2.6 (192-2, unique among Diplodocoidea)
* (3) posterior cervical postzygapophyses terminate in front of the posterior edge of the centrum (200-1, unique within Diplodocinae)

XXX Jensen’s Jensen/Jensen Quarry, Jensen

XXX BYU field jacket 3GR, excavated 1966 from Jensen/Jensen

XXX Contains three ?consecutive *Barosaurus* cervicals, designated A, B and C.

XXX Why this is *Barosaurus*.

XXX Difficulty of photographing large bones. Distance and perspective distortion. Photo of me up the ladder shooting down.

XXX Why BYU 9024 is morphologically indistinguishable from *Barosaurus*.

# Results

XXX Sizes of A, B and C.

XXX Serial position of A, B and C.

XXX Size of the 3BJ animal

XXX Size of BYU 9024

XXX Serial position of BYU 9024

## *Barosaurus* compared with *Diplodocus*

*Barosaurus* closely resembles its near relative *Diplodocus* in its postcervical skeleton, differing primarily in cervical characters. This is most notable in the elongation of the neck: it is 40% longer than the 6.1 m neck of the well known *Diplodocus carnegii* holotype CM 84, casts of which grace a dozen museums around the world. The best known *Barosaurus* specimen and the best known *Diplodocus* specimen (AMNH 6341 and CM 84 respectively) are almost exactly the same size in their torso and limbs, differing only in that the former has a longer neck and the latter a longer tail (Figure A). Otherwise proportional differences are minor: *Barosaurus* is slightly taller at the shoulders and slightly less tall at the hips. Since the neck and tail typically accounts for no more than 20% of the mass of a sauropod (see e.g. Taylor 2009: table 4), these two individuals likely weighed almost exactly the same.

As the well known AMNH 6341 specimen of *Barosaurus* is about the same size as the Carnegie *Diplodocus*, which massed perhaps 12 tonnes (Wedel 2005:220) — as since the ROM and Utah mounts are of comparable size such that AMNH material can be readily incorporated into them — it is generally accepted that all the well-known *Barosaurus* individuals massed on the order of 12 tonnes.

XXX Size of the BYU 9024 animal

XXX Comparison of neck with total height of Berlin brachiosaur

# Discussion

XXX Does this mean that *Supersaurus* is *Barosaurus*? No, it's not that easy.

XXX Ecological implications of rare super-giant individuals

# Acknowledgements

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We are grateful to Rick Hunter (Western Palaeo Labs) for allowing us access to privately owned *Barosaurus* cervicals at the North American Museum of Ancient Life.

Scott Hartman has raised the bar for scientifically accurate skeletal reconstructions of dinosaurs, and we are grateful to him for allowing us to use his *Diplodocus carnegii* and *Barosaurus lentus* reconstructions for the comparison in Figure A, and for permission to cite personal communication.

We thank David Evans (Royal Ontario Museum) for information about the ROM’s mounted *Barosaurus* specimen and Randall B. Irmis for information about the composite mounted skeleton at the Natural History Museum of Utah, and for permission to cite personal communication. We also thank Garth Dallman and Peter May (Research Casting International) for permission to cite personal communications.

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# Figure Captions

**Figure A.** Relative size and proportions of the best known *Barosaurus* and *Diplodocus* specimens. In black, *Barosaurus lentus* AMNH 6341; in grey, *Diplodocus carnegii* CM 84. Skeletal reconstructions by Scott Hartman, used by kind permission. *Barosaurus* has a notably longer neck than *Diplodocus* and a shorter tail. It is also somewhat taller at the shoulders and less so at the hips. Otherwise their size and proportions are very similar.

**Figure B.** The mounted skeleton of *Barosaurus lentus* AMNH 6341 in the Theodore Roosevelt Rotunda of the American Museum of Natural History, New York. XXX to be sourced.

**Figure C.** Juvenile *Barosaurus* sp. AMNH 7535, cervical vertebra 9 in left lateral view, red-cyan anaglyph. XXX not yet cited.

**Figure D.** Juvenile *Barosaurus* sp. AMNH 7535, cervical vertebra 7 in left lateral view, red-cyan anaglyph. The vertebra is shown with dorsal to the top, since the available photographs vary slightly in their dorsal-vental perspective, not their anterior-posterior perspective. XXX not yet cited.

**Figure E.** Cervical vertebra 9 of two *Barosaurus* specimens compared in dorsal view (anterior to left). **A.** juvenile *Barosaurus* sp. AMNH 7535. **B.** adult *Barosaurus lentus* AMNH 6341. Note that the latter has features characteristic of *Barosaurus* cervicals, including: broad prezygapophyseal facets set on broad rami; “hinged” prezygapophyseal rami, in which a longitudinal ridge separates two flat laminae, the PRDL laterally and the SPRL medially; “swept-out” lateral processes that project laterally, and which are met anteriorly by an elegantly curved PRDL and posteriorly by an elegantly curved PODL; a “thumb groove” separating the prezygapophyseal facet from a laterally positioned eminence on the prezygapophyseal ramus; a “U”-shaped notch where the two SPRLs meet medially; and flaring postzygapophyseal rami. All these features are absent in AMNH 7535. These missing features can be in part explained by lateral crushing, but the vertebra shows little sign of extensive crushing. Their absence may be due to the juvenile status of the individual: at approximate 330 mm in total centrum length, its C9 is less than half the size of that of AMNH 6341 at 685 mm (McIntosh 2005:table 2.1). Or they may indicate that AMNH 7535 is not in fact *Barosaurus*, or at least not *Barosaurus lentus*.

# Tables

## Table A

Measurements of the cervical vertebrae of the small specimen AMNH 7535 referred to *Barosaurus* sp. ACH = anterior centrum height, ACW = anterior centrum width, PCH = posterior centrum height, PCW = posterior centrum width, CL = centrum length (including anterior condyle), FL = functional length (excluding anterior condyle), TL = total length (including overhanging zygapophyses), TH = total height. Totals are calculated for centrum length and functional lengths across the vertebrae C2–C7, the ones that are scaled (see text) to act as proxies for the missing anterior cervicals of AMNH 6341.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Vertebra** | **ACH** | **ACW** | **PCH** | **PCW** | **CL** | **FL** | **TL** | **TH** |
| C2 | 28 | 22 | 29 | 25 | 85 | 74 | 92 | 73 |
| C3 | 17 | 28 | 24 | 36 | 104 | 89 | 111 | 86 |
| C4 | 21 | 24 | 34 | 40 | 137 | 128 | 158 | 92 |
| C5 | 22 | 37 | 39 | 47 | 168 | 152 | 189 | 102 |
| C6 | 36 | 48 | 59 | 51 | 200 | 184 | 215 | 122 |
| C7 | 40 | 37 | 56 | 66 | 272 | 251 | 305 | 148 |
| C8 | 46 | 40 | 62 | 69 | 313 | 292 | 357 | 157 |
| C9 | 50 | 56 | 75 | 67 | 362 | 326 | 413 | 167 |
| C2–C7 Total |  |  |  |  | 966 | 878 |  |  |

## Table B

Estimations of the neck length of *Barosaurus lentus* AMNH 6341. Nine estimates are made: three methods (see text for details) each assessed under three interpretations: “short” assumes that the condyle of each vertebra is fully buried in the cotyle of its predecessor, i.e. that there is negligible intervertebral cartilage; “long” assumes that condyles approach but do not penetrate the cotyles due to the presence of thick cartilage as in for example modern camels (Taylor and Wedel 2013:figures 5, 21); “medium” represents a compromise interpretation in which condyles penetrate to half the depth of the corresponding cotyles with intervertebral cartilage filling the remaining space.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Estimation method** | **Interpretation** | **C8–C16 length** | **C1–C7 estimate** | **Total length** |
| 1. Scaled juvenile | Short | 6166 | 1738 | 7904 |
|  | Medium | 6550 | 1821 | 8371 |
|  | Long | 6933 | 1903 | 8836 |
| 2. *Diplodocus* neck | Short | 6166 | 2356 | 8522 |
|  | Medium | 6550 | 2506 | 9056 |
|  | Long | 6933 | 2655 | 9588 |
| 3. Artistic intuition | Short | 6166 | 2142 | 8308 |
|  | Medium | 6550 | 2275 | 8825 |
|  | Long | 6933 | 2408 | 9341 |