**Appendix S1: Methods and results for dinosaur body mass estimates**

*from Benson RBJ, Hunt G, Carrano MT, Campione N. 2017. Cope’s rule and the adaptive landscape of dinosaur body size evolution. Palaeontology.*

We estimated the masses of dinosaurs in kilograms, using the scaling relationship between body mass and minimum stylopodial shaft circumferences derived from extant tetrapods (Campione & Evans 2012; Campione *et al*. 2014).

The equation for predicting body mass in quadrupedal tetrapods uses humeral and femoral shaft minimum circumferences (HC and FC; Campione & Evans 2012), whereas the formula for predicting body mass in bipedal taxa uses only the femoral shaft minimum circumference with a correction factor (FC + 20.5; Campione *et al*. 2014):

[1] massquadruped = (10^(2.749\*log10(FC + HC) – 1.104)) / 1000

[2] massbiped = (10^(2.749\*log10(FC \* 20.5) – 1.104)) / 1000

In our previous work, stylopodial measurements were available for 441 dinosaurs, including those taxa for which shaft diameters were known but circumferences were not measured and not available in the published literature (Benson *et al*. 2014). In the present work, we added several recently described dinosaur specimens to our dataset (e.g. Lacovara *et al*. 2014; Lamanna *et al*. 2014; Y.-N. Lee *et al*. 2014), and extended the number of mass estimates to 584 dinosaurs (525 adults) using regression models, including phylogenetic prediction based on phylogenetic generalised least squares regression (Garland & Ives 2001).

For each comparison of variables, Aikake’s information criterion for finite sample sizes (AICc; Sugiura 1978; Burnham & Anderson 2004) was used to select the best model by: (1) varying the strength of phylogenetic signal; (2) estimating a non-zero intercept or setting the intercept to zero; and where relevant (3) including stance (quadrupedal or bipedal) or clade assignment (e.g. titanosaur | non-titanosaur; hadrosauroid | non-hadrosauroid; stegosaur | ankylosaur) as a covariate or interaction term.

Phylogenetic signal in the relationships among variables was assessed by comparing three types of regression model using generalised least squares: (1) no phylogenetic signal (equivalent to ordinary least squares, or Pagel’s lambda = 0; Pagel 1999); (2) strong phylogenetic signal (implemented using a phylogenetic variance-covariance matrix based on our phylogeny and assuming Brownian motion, or Pagel’s lambda = 1.0; this is phylogenetic regression of Garland & Ives 2001); (3) intermediate phylogenetic signal (estimating the value of lambda during model fitting; Paradis *et al*. 2004; Pinheiro *et al*. 2013). Data were log10-transformed in all analyses. Taxa known from juveniles, or composite data from multi-individual accumulations (e.g. bonebeds), were excluded from analyses used to determine predictive relationships among variables when those variables represented different skeletal elements. In other words, data from juveniles and bonebeds were only used for comparisons of different measurements from a single skeletal element (i.e. comparison of femoral length to minimum femoral shaft circumference). Varying the tree topology or node divergence time calibration method had little impact on our results.

Masses of 107 quadrupedal or facultatively quadrupedal dinosaurs, and 143 bipedal dinosaurs (total 250 dinosaurs) could be estimated from directly measured shaft circumferences. This was initially done treating facultative quadrupeds as quadrupedal, and our results were insensitive to the treatment of such taxa.

**Anatomical abbreviations.** HAP, humeral minimum anteroposterior shaft diameter; HC, humeral minimum shaft circumference; HCoval, humeral minimum shaft circumference estimated from shaft diameters using equation [3] below; HL, humeral length; HML, humeral minimum mediolateral shaft diameter; FAP, femoral minimum anteroposterior shaft diameter; FC, femoral minimum shaft circumference; FCoval, femoral minimum shaft circumference estimated from shaft diameters using equation [3] below; FL, femoral length; FML, femoral minimum mediolateral shaft diameter; RC, radius minimum shaft circumference; RL, radius length; TC, tibia minimum shaft circumference; TL, tibia length.

**Estimating stylopodial shaft circumferences when both diameters are known.** We calculated the circumference of an oval with diameters equal to the measured diameters of each femoral or humeral shaft using equation [3] below.

[3] circumferenceoval = π\*((3\*(a+b))-(((3\*a+b)\*(a+3\*b))^0.5))

These oval circumference calculations were used to estimate the minimum shaft circumference using regression. Regression models for measured femoral circumference (FC) against its calculated oval perimeter (FCoval) among Dinosauria were compared using AICc: (1) varying the strength of phylogenetic signal; (2) estimating a non-zero intercept or setting the intercept to zero; and (3) including stance (quadrupedal or bipedal) as a covariate or interaction term. A single non-phylogenetic regression relationship between FC and FCoval for all dinosaurs was overwhelmingly the best model (Table S1; AICc-weight > 0.99; R2 = 0.996; N = 108), and a model that additionally included stance as a covariate has an AICc-weight of only 0.01.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FCoval + intercept | >0.99 | 108 | 0.996 | 0.066 | 0.981 | <0.001 | 0.00 |
| 2 | FC ~ FCoval | <0.01 | 108 | 0.995 | - | 1.008 | <0.001 | 0.00 |
| 3 | FC ~ FCoval + clade + intercept | <0.01 | 108 | 0.995 | 0.070 | 0.980 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HCoval | 0.77 | 47 | 0.992 | - | 1.009 | <0.001 | 0.00 |
| 2 | HC ~ HCoval + intercept | 0.15 | 47 | 0.992 | 0.059 | 0.984 | <0.001 | 0.00 |
| 3 | HC ~ HCoval | 0.05 | 47 | 0.981 | - | 1.009 | <0.001 | -0.04 |
|  |  |  |  |  |  |  |  |  |

**Table S1.** Best regression models (based on AICc-weight) to predict log10(FC) and log10(HC) from log10(FCoval) and log10(HCoval) respectively, in both bipedal and quadrupedal taxa. Abbreviations: N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999). Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The strong, non-phylogenetic relationship between FC and FCoval results in equation [4], which was used to estimate FC from FCoval across Dinosauria. Note that equation [4] was derived from the complete set of N = 133 specimens for which FC and FCoval were known, whether or not they were included in the phylogeny, using more of the data than the AICc-weight comparison between phylogenetic and non-phylogenetic models described above.

[4] log10(FC) = 0.983 \* log10(FCoval) + 0.060

A similar approach to humeral circumference also provided strong support (AICc-weight = 0.77; R2 = 0.992; N = 47) for a single non-phylogenetic relationship between measured minimum shaft circumference (HC) and an oval perimeter estimate (HCoval) in all quadrupedal dinosaurs, irrespective of phylogenetic affinities (Table S1). Therefore, equation [5] was used to estimate HC from HCoval based on the complete set of N = 61 specimens for which HC and HCoval were known:

[5] log10(HC) = 1.009 \* log10(HCoval)

Both relationships were highly explanatory (R2 > 0.990) so shaft circumferences estimated using shaft diameters are reliable. The absence of phylogenetic, stance- or clade-dependent signal in both was inferred from the fact that phylogenetic regression models, and models including stance or clade assignment as a covariate or interaction term, received negligible AICc weights (and therefore are not shown in Table S1). This suggests that the relationship between pairs of stylopodial shaft diameters and circumferences is highly physically-constrained, and allows us to estimate unmeasured femoral and humeral shaft circumferences in taxa for which anteroposterior and mediolateral shaft diameters were measured using equations [4] and [5] above. In total, 157 humeral circumferences were measured, and 47 more were estimated from diameters using equations [3] and [5]; 300 femoral circumferences were measured and 71 more were estimated from diameters using equations [3] and [4].

**Estimating femoral shaft circumference in bipedal dinosaurs**. We determined the best bivariate regression model to predict minimum femoral shaft circumference (FC) in bipedal dinosaurs using combinations of the measured variables: femoral mediolateral shaft diameter (FML), femoral anteroposterior shaft diameter (FAP), femoral length (FL), tibia length (TL) and minimum tibia shaft circumference (TC).

Initial analyses comparing variables relating to the femur (FL, FAP, FML) using the sample of taxa for which all these measurements were available (N = 41), indicated that FML was the best predictor of FC. In fact, a non-phylogenetic regression model in which FML and an intercept explain FC received an AICc-weight > 0.99 when compared to the full set of other models explaining FC in terms of either FL, FML or FAP. Including other variables in addition to FML, in a multivariate framework, did not improve the AICc score, although FAP and FL also produce reliable estimates of FC (Table S2). Over the smaller sample of taxa for which TC was also available (N = 25), AICc weights indicate that TC predicts FC better than FAP or FL, but not as well as FML, and TL predicts FC worse than any femoral measurement over a sample size of N = 31.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept | >0.99 | 57 | 0.991 | 0.604 | 0.943 | <0.001 | 0.00 |
| 2\*\* | FC ~ FML + clade1 + intercept | <0.01 | 57 | 0.990 | 0.606 | 0.944 | <0.001 | 0.00 |
| 3\*\* | FC ~ FML + clade1 | <0.01 | 57 | 0.990 | - | 0.944 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1\*\* | FC ~ FL + clade1 + intercept | 0.49 | 97 | 0.972 | -0.711 | 1.130 | <0.001 | 0.00 |
| 2\*\* | FC ~ FL + clade1 | 0.49 | 97 | 0.972 | - | 1.130 | <0.001 | 0.00 |
| 3 | FC ~ FL \* clade1 | 0.01 | 97 | 0.971 | -0.467 | 1.024 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP + intercept | >0.99 | 51 | 0.980 | 0.489 | 1.024 | <0.001 | 0.00 |
| 2 | FC ~ FAP + intercept | <0.01 | 51 | 0.969 | 0.515 | 1.009 | <0.001 | -0.06 |
| 3 | FC ~ FAP + clade1 + intercept | <0.01 | 51 | 0.975 | 0.488 | 1.024 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1\*\* | FC ~ TL + clade1 + intercept | 0.45 | 67 | 0.940 | -1.264 | 1.353 | <0.001 | 0.00 |
| 2\*\* | FC ~ TL + clade1 | 0.45 | 67 | 0.940 | - | 1.353 | <0.001 | 0.00 |
| 3 | FC ~ TL \* clade1 | 0.04 | 67 | 0.940 | -0.746 | 1.122 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.82 | 40 | 0.981 | - | 1.033 | <0.001 | 0.00 |
| 2 | FC ~ TC | 0.10 | 40 | 0.980 | - | 1.035 | <0.001 | 0.15 |
| 3 | FC ~ TC + intercept | 0.07 | 40 | 0.980 | 0.059 | 1.005 | <0.001 | 0.00 |

**Table S2.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FL), log10(FAP), log10(TL) and log10(TC) in bipedal dinosaurs. Abbreviations and notes: 1, “clade” is a categorical covariate denoting assignment to Ornithischia, Sauropodomorpha or Theropoda, see equations 9–11 in text for clade coefficient estimates; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

Investigation of these relationships using the larger sample of taxa available for comparison of FC with a single other variable indicated that a non-phylogenetic regression model including FML as an explanatory variable predicted FC well in bipedal dinosaurs (Table S2; AICc-weight > 0.99 when compared to other models including FML; R2 = 0.991; N = 57). Equation [6] therefore was used to estimate FC from FML in bipedal dinosaurs, based on the complete set of N = 71 specimens for which FC and FML were both known, regardless of whether they could be included in our phylogeny. Equation [6] allows 50 estimates of FC in bipedal taxa where FC was not measured directly and FCoval could not be calculated (i.e. FML was measured, but FAP was not).

[6] log10(FC) = 0.949 \* log10(FML) + 0.594

A non-phylogenetic regression against TC also predicts FC well in bipedal dinosaurs (Table S2; AICc-weight = 0.82 when compared to other models including TC; R2 = 0.981; N = 40), and introduction of a weak phylogenetic signal (lambda = 0.15; AICc-weight = 0.10) or a non-zero intercept (AICc-weight = 0.07) do not improve the AICc score. Equation [7] was therefore used to estimate FC from TC in bipedal dinosaurs, based on the complete set of N = 45 specimens for which FC and TC were both known, regardless of whether they were included in our phylogeny. This equation allows four additional estimates of FC in bipedal taxa that could not be made using equations [4]–[6] above.

[7] log10(FC) = 1.033 \* log10(TC)

The non-phylogenetic regression of FC on FAP (Table S2; AICc-weight > 0.99 when compared to other models including; R2 = 0.980; N = 51) and allows 56 additional estimates of FC that could not be obtained from FCoval, FML or TC. These estimates were made using equation [8] below, based on the complete set of N = 64 specimens for which both FC and FAP were known, regardless of whether they had been included in our phylogeny.

[8] log10(FC) = 1.030 \* log10(FAP) + 0.478.

The best model for prediction of FC from FL includes clade (Ornithischia | Sauropodomorpha | Theropoda) as a covariate, and models including a zero or non-zero intercept receive approximately equal AICc weights (= 0.49). Indeed both models are mathematically identical, and have a high summed AICc-weight (= 0.98). Under either model FL predicts FC well (R2 = 0.972; N = 97), and we arbitrarily use the zero intercept model. This model is better than any model in which the relationship between FL and FC evolves under Brownian motion (lambda = 1.0), or includes even weak phylogenetic signal (lambda > 0), which receive negligible AICc weights (< 0.001). Using the clade-specific relationships between FL and FC in bipedal dinosaurs based on the complete data for all specimens in which both values were known (N = 125; equations [9]–[11] below) allowed 31 additional mass estimates of bipedal dinosaurs, not possible using equations [4]–[8].

[9] log10(FC) = 1.132 \* log10(FL) - 0.7130 in Ornithischia

[10] log10(FC) = 1.132 \* log10(FL) - 0.7659 in Sauropodomorpha

[11] log10(FC) = 1.132 \* log10(FL) - 0.8429 in Theropoda

As with FL, the best model predicting FC from TL includes “clade” (Ornithischia | Sauropodomorpha | Theropoda) as a covariate, and models including a zero or non-zero intercept receive approximately equal AICc weights (= 0.45) and are mathematically identical. Even under these models, TL is a worse predictor of FC than any other measurement of the femur or tibia (R2 = 0.94; N = 67). The clade-specific equations derived from the complete set of N = 86 specimens in which both FC and TL were known indicate that ornithischians and sauropodomorphs have proportionally longer tibiae compared to their femoral robustness than do theropods (equations [12]–[14] below). These equations allow 13 additional mass estimates of bipedal dinosaurs, not possible using equations [4]–[11].

[12] log10(FC) = 1.333 \* log10(TL) - 1.215 in Ornithischia

[13] log10(FC) = 1.333 \* log10(TL) - 1.185 in Sauropodomorpha

[14] log10(FC) = 1.333 \* log10(TL) - 1.386 in Theropoda

**Quadrupedal dinosaurs—identifying taxa as quadrupeds.** As in Benson *et al*. (2014), dinosaurs were considered to be primitively bipedal. Thus, the masses of theropods (including Mesozoic birds), many ornithischians, and most non-sauropodan sauropodomorphs were estimated using equation [2] above, from Campione *et al*. (2014). Within Sauropodomorpha, the clade comprising *Melanorosaurus*, *Camelotia*, and *Lessemsaurus* plus Sauropoda was considered to be quadrupedal (e.g. Yates *et al*. 2010). Riojasauridae (*Riojasaurus* + *Eucnemesaurus*), and the clade of *Jingshanosaurus* and all taxa more closely related to Sauropoda than to *Jingshanosaurus* (e.g. Aardonyx), were considered to be at least facultatively quadrupedal (Yates *et al*. 2010; Bonaparte & Pumares 1995; Bonnan 2003; Yates & Kitching 2003; Yates 2007).

Three ornithischian clades were also considered to be quadrupedal: (1) the clade comprising most thyreophorans (stegosaurs, ankylosaurs, plus *Scelidosaurus*); (2) the clade comprising most ceratopsians (Leptoceratopsidae and all taxa more closely related to Ceratopsidae, except *Cerasinops* and *Udanoceratops* were treated as certainly quadrupedal; neoceratopsians outside this clade, *Cerasinops*, and *Udanoceratops*, were considered to be at least facultatively quadrupedal; Chinnery 2004, 2007; Zhao *et al*. 2013); and (3) the clade comprising Hadrosauroidea plus some other iguanodontians (*Mantellisaurus*, *Iguanodon*, and all taxa more closely related to Hadrosauroidea) were treated as certainly quadrupedal. Iguanodontians outside this clade were considered to be at least facultatively quadrupedal (Norman 1980, 1986; Maidment *et al*. 2012; Maidment & Barrett 2012). Benson *et al*. (2014) performed analyses treating facultative quadrupeds as bipeds, and all iguanodontians as bipeds. This has little effect on evolutionary model fitting results. Here, we treat all quadrupeds and facultative quadrupeds as quadrupedal for the purposes of mass estimation, therefore using equation [1] above, from Campione & Evans (2012).

**Quadrupedal dinosaurs—scaling relationships.** Different groups of quadrupedal dinosaurs have different interlimb and intra-hindlimb proportions, even within Ornithischia (Maidment *et al*. 2012). This is indicated by the scaling relationship of FC with measurements of the humerus and the tibia (Table S3), and scaling relationships of HC with measurements of the radius and femur (Table S4), for which the best models according to AICc include an intermediate amount of phylogenetic signal (lambda ~ 0.60 to 0.75; exceptionally 0.91), or include clade (Sauropodomorpha | Ankylosauria | Stegosauria | Iguanodontia | Ceratopsia) as a covariate, and explain a relatively low amount of variance (R2 < 0.890).

These relationships are investigated for individual clades below. Nevertheless, FC has a strong, non-phylogenetic relationship with FML and with FL across quadrupedal dinosaurs, and this relationship is not improved by the addition of phylogenetic signal, or clade as a covariate (Table S3; summed AICc weights > 0.92 for non-phylogenetic models). When models are compared over the set of N = 71 taxa for which FC and both FL and FML are known, models using only FML have a summed AICc-weight > 0.99, demonstrating that FML provides a better prediction of FC than does FL.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept | 0.98 | 76 | 0.960 | 0.689 | 0.889 | <0.001 | 0.00 |
| 2 | FC ~ FML + intercept | 0.02 | 76 | 0.910 | 0.643 | 0.907 | <0.001 | 0.43 |
| 3 | FC ~ FML + clade1 + intercept | <0.01 | 76 | 0.957 | 0.574 | 0.931 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FL + intercept | 0.93 | 116 | 0.947 | -0.377 | 0.998 | <0.001 | 0.00 |
| 2\*\* | FC ~ FL + clade1 + intercept | 0.03 | 116 | 0.948 | -0.343 | 0.993 | <0.001 | 0.00 |
| 3\*\* | FC ~ FL + clade1 | 0.03 | 116 | 0.948 | - | 0.993 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP + intercept | >0.99 | 67 | 0.871 | 0.676 | 0.956 | <0.001 | 0.38 |
| 2 | FC ~ FAP + intercept | <0.01 | 67 | 0.907 | 0.618 | 0.986 | <0.001 | 0.00 |
| 3 | FC ~ FAP + clade1 + intercept | <0.01 | 67 | 0.909 | 0.735 | 0.937 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HC + intercept | 0.84 | 73 | 0.886 | 0.256 | 0.933 | <0.001 | 0.74 |
| 2 | FC ~ HC | 0.15 | 73 | 0.877 | - | 1.036 | <0.001 | 0.74 |
| 3 | FC ~ HC + clade1 | <0.01 | 73 | 0.884 | 0.197 | 0.936 | <0.001 | 0.50 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HL | 0.79 | 73 | 0.725 | - | 0.934 | <0.001 | 0.68 |
| 2 | FC ~ HL + intercept | 0.14 | 73 | 0.720 | -0.095 | 0.966 | <0.001 | 0.65 |
| 3 | FC ~ HL | 0.06 | 73 | 0.845 | - | 0.918 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1\*\* | FC ~ TL + clade1 | 0.42 | 61 | 0.838 | - | 0.984 | <0.001 | 0.00 |
| 2\*\* | FC ~ TL + clade1 + intercept | 0.42 | 61 | 0.838 | -0.147 | 0.984 | <0.001 | 0.00 |
| 3 | FC ~ TL | 0.14 | 61 | 0.645 | - | 0.912 | <0.001 | 0.60 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.67 | 38 | 0.736 | - | 1.036 | <0.001 | 0.62 |
| 2 | FC ~ TC + intercept | 0.17 | 38 | 0.732 | -0.182 | 1.108 | <0.001 | 0.68 |
| 3 | FC ~ TC | 0.10 | 38 | 0.708 | - | 1.019 | <0.001 | 1.00 |

**Table S3.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FL), log10(FAP), log10(HC), log10(HL), log10(TL) and log10(TC) in quadrupedal dinosaurs. Abbreviations and notes: 1, “clade” is a categorical covariate denoting assignment to Sauropodomorpha, Ankylosauria, Stegosauria, Iguanodontia or Ceratopsia; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The non-phylogenetic relationships of FC with FML and FL allowed us to estimate FC from FML using the ordinary least squares regression relationship derived from the complete set of N = 93 taxa for which both FC and FML were known, regardless of whether they were included in our phylogeny (R2 = 0.964; equation [15]), and the relationship of FC with FL derived from the full set of 143 taxa for which both values were known (R2 = 0.950; equation [16]). These relationships allowed us to estimate femoral shaft circumferences using FML in 34 quadrupedal taxa for which FC could not be estimated from the oval perimeter estimate (equation [4]), and using FL in 30 taxa for which FC also could not be estimated using FML (equation [15]).

[15] log10(FC) = 0.889 \* log10(FML) - 0.686

[16] log10(FC) = 1.002 \* log10(FL) - 0.390

Humeral diameters (HML, HAP) have strong, non-phylogenetic relationships with HC in quadrupedal dinosaurs. In contrast, HL and RL have weaker, phylogeny-dependent relationships with HC (Table S4), which are further below. Radial circumference (RC) has a strong, phylogeny-dependent relationship with HC (Table S4) and is also investigated further below within individual clades.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | HC ~ HML + intercept | 0.79 | 63 | 0.980 | 0.641 | 0.908 | <0.001 | 0.00 |
| 2 | HC ~ HML + intercept | 0.21 | 63 | 0.960 | 0.613 | 0.919 | <0.001 | 0.50 |
| 3 | HC ~ HML + clade + intercept | <0.01 | 63 | 0.946 | 0.639 | 0.907 | <0.001 | 0.63 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HAP + intercept | >0.99 | 48 | 0.913 | 0.515 | 1.042 | <0.001 | 0.00 |
| 2\*\* | HC ~ HAP + clade + intercept | <0.01 | 48 | 0.903 | 0.728 | 0.916 | <0.001 | 0.00 |
| 3\*\* | HC ~ HAP + clade | <0.01 | 48 | 0.903 | - | 0.916 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HL | 0.29 | 94 | 0.787 | - | 0.872 | <0.001 | 0.87 |
| 2\*\* | HC ~ HL \* clade + intercept | 0.29 | 94 | 0.922 | 0.414 | 0.728 | <0.001 | 0.00 |
| 3\*\* | HC ~ HL \* clade | 0.29 | 94 | 0.922 | - | 0.728 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FC | 0.92 | 73 | 0.891 | - | 0.961 | <0.001 | 0.74 |
| 2 | HC ~ FC + intercept | 0.08 | 73 | 0.886 | -0.034 | 0.974 | <0.001 | 0.74 |
| 3 | HC ~ FC + clade + intercept | 0.00 | 73 | 0.884 | -0.017 | 0.986 | <0.001 | 0.45 |
|  |  |  |  |  |  |  |  |  |
| 1\*\* | HC ~ FL + clade + intercept | 045 | 69 | 0.895 | -0.187 | 0.917 | 0.157 | 0.00 |
| 2\*\* | HC ~ FL + clade | 0.45 | 69 | 0.895 | - | 0.917 | - | 0.00 |
| 3 | HC ~ FL | 0.05 | 69 | 0.763 | - | 0.829 | - | 0.63 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RC | 0.86 | 26 | 0.937 | - | 1.091 | <0.001 | 0.91 |
| 2 | HC ~ RC + intercept | 0.11 | 26 | 0.933 | 0.102 | 1.046 | <0.001 | 0.90 |
| 3 | HC ~ RC | 0.03 | 26 | 0.922 | - | 1.093 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RL + intercept | 0.52 | 52 | 0.554 | 0.471 | 0.746 | <0.001 | 0.65 |
| 2 | HC ~ RL | 0.38 | 52 | 0.529 | - | 0.920 | <0.001 | 0.72 |
| 3 | HC ~ RL + clade + intercept | 0.05 | 52 | 0.778 | 0.572 | 0.707 | <0.001 | 0.00 |

**Tables S4.** Best regression models (based on AICc-weight) to predict log10(HC) from log10(HML), log10(HAP), log10(HL), log10(FC), log10(FL), log10(RC) and log10(RL) in quadrupedal dinosaurs. Abbreviations and notes: 1, “clade” is a categorical covariate denoting assignment to Sauropodomorpha, Ankylosauria, Stegosauria, Iguanodontia or Ceratopsia; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The non-phylogenetic relationships of HC with HML and HAP allow us estimate HC in quadrupedal dinosaurs based on the complete sets of N = 80 (HML; R2 = 0.980) and N = 62 (HAP; R2 = 0.915) taxa for which the relevant measurements were known. These allowed us to estimate HC using HML in 40 taxa for which HCoval was not known, and using HAP in 7 taxa for which neither HCoval or HAP were known.

[17] log10(HC) = 0.904 \* log10(HML) - 0.649

[18] log10(HC) = 1.075 \* log10(HAP) - 0.464

When models are compared over the set of N = 47 taxa for which HC and both HML and HAP are known, models based on HML have a combined AICc-weight > 0.99, indicating that HML is the best predictor of HC.

**Quadrupedal sauropodomorphs.** Femoral shaft mediolateral diameter (FML) and humeral shaft circumference (HC) provide the best estimates of FC in quadrupedal sauropodomorphs, based on strong, non-phylogenetic relationships (Table S5). Relationships of FC with other limb measurements, such as FL, FAP, HL, TL and TC, are substantially weaker (R2 <0.872), and the relationship between FC and measurements of the tibia includes phylogenetic signal.

Femoral eccentricity (the ratio FML:FAP) has been suggested to be higher in titanosaurian sauropods (Wilson & Carrano 1999). This might introduce phylogenetic signal to the relationship between FC and FML. Including a binary categorical covariate distinguishing titanosauriforms from non-titanosauriforms or titanosaurs from non-titanosaurs does not improve the model (negligible AICc-weight < 0.01 and not appearing in Table S5). By contrast, models including a binary categorical covariate distinguishing titanosaurians from non-titanosaurians have non-negligible AICc weights (AICc-weight = 0.12 for the best model including the “clade” term; Table S5). However, because there is little consensus on phylogenetic relationships among titanosaurians, few of these taxa are included in our tree, so only two titanosaurian sauropods are included in the set of N = 30 taxa included in our phylogeny for which FC and FML are known. Therefore, we also performed model comparisons excluding phylogenetic models, and in which a larger sample of titanosaurians could be included (N = 9 titanosaurians of a total N = 45 sauropods; Table S5). In this analysis, the best models including a “clade” covariate term also had non-negligible AICc-weight (= 0.26), although these were lower than those not including the “clade” variable (AICc-weight = 0.47). Within these models, the coefficient of the non-titanosaurian term is 0.51192 whereas that of the titanosaurian term is 0.50434, amounting to a difference of 0.00758. This suggests that titanosaurian femora may be slightly more eccentric than those of other sauropods, but that further data are required to statistically confirm that this difference is distinct from an allometric trend of increasing eccentricity with body size seen across sauropods (e.g. Henderson 2006).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept(1) | 0.50 | 30 | 0.980 | 0.523 | 0.956 | <0.001 | 0.00 |
| 2 | FC ~ FML + intercept(1) | 0.45 | 30 | 0.981 | 0.529 | 0.949 | <0.001 | 0.29 |
| 3 | FC ~ FML + intercept(1) | 0.03 | 30 | 0.977 | 0.504 | 0.958 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FML + intercept | 0.35 | 30 | 0.980 | 0.523 | 0.956 | <0.001 | 0.00 |
| 2 | FC ~ FML + intercept | 0.32 | 30 | 0.981 | 0.529 | 0.949 | <0.001 | 0.29 |
| 3 | FC ~ FML + clade2 | 0.12 | 30 | 0.982 | - | 0.956 | <0.001 | -0.30 |
| 4\*\* | FC ~ FML + clade2 + intercept | 0.07 | 30 | 0.980 | 0.515 | 0.960 | <0.001 | 0.00 |
| 5\*\* | FC ~ FML + clade2 | 0.07 | 30 | 0.980 | - | 0.960 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FML + intercept | 0.47 | 45 | 0.984 | - | 0.961 | <0.001 | 0.003 |
| 2\*\* | FC ~ FML + clade2 | 0.26 | 45 | 0.984 | - | 0.960 | <0.001 | 0.003 |
| 3\*\* | FC ~ FML + clade2 + intercept | 0.26 | 45 | 0.984 | 0.512 | 0.960 | <0.001 | 0.003 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FL | 0.37 | 44 | 0.871 | - | 0.901 | <0.001 | 0.60 |
| 2 | FC ~ FL | 0.28 | 44 | 0.860 | - | 0.881 | <0.001 | 0.00 |
| 3 | FC ~ FL + intercept | 0.21 | 44 | 0.865 | -0.317 | 0.982 | <0.001 | 0.00 |
| 4 | FC ~ FL + intercept | 0.11 | 44 | 0.871 | -0.206 | 0.968 | <0.001 | 0.62 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP + intercept | 0.74 | 21 | 0.767 | 0.846 | 0.897 | <0.001 | 0.00 |
| 2 | FC ~ FAP + intercept | 0.16 | 21 | 0.767 | 0.715 | 0.955 | <0.001 | -0.10 |
| 3 | FC ~ FAP + clade + intercept | 0.03 | 21 | 0.726 | 0.830 | 0.899 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HC | 0.83 | 30 | 0.932 | - | 1.032 | <0.001 | 0.00 |
| 2 | FC ~ HC + intercept | 0.12 | 30 | 0.928 | 0.105 | 0.993 | <0.001 | 0.00 |
| 3 | FC ~ HC | 0.02 | 30 | 0.916 | - | 1.031 | <0.001 | 0.03 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HL | 0.26 | 32 | 0.673 | - | 0.910 | <0.001 | 0.00 |
| 2 | FC ~ HL + intercept | 0.22 | 32 | 0.693 | 0.437 | 0.766 | <0.001 | 0.00 |
| 3 | FC ~ HL + clade + intercept | 0.07 | 32 | 0.695 | 0.310 | 0.815 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TL | 0.25 | 24 | 0.654 | - | 0.964 | <0.001 | 0.87 |
| 2 | FC ~ TL | 0.25 | 24 | 0.643 | - | 0.964 | <0.001 | 1.00 |
| 3 | FC ~ TL + intercept | 0.20 | 24 | 0.672 | 0.480 | 0.792 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.47 | 12 | 0.646 | - | 1.081 | <0.001 | 1.00 |
| 2 | FC ~ TC | 0.22 | 12 | 0.613 | - | 1.083 | <0.001 | 1.03 |
| 3 | FC ~ TC + intercept | 0.14 | 12 | 0.663 | 0.109 | 1.040 | <0.001 | 1.00 |

**Table S5.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FL), log10(FAP), log10(HC), log10(HL), log10(TL) and log10(TC) in quadrupedal sauropodomorphs. Abbreviations and notes: 1, comparisons including “clade” as a categorical covariate denoting assignment to comparing titanosauriforms to non-titanosauriforms (written in parentheses as models including this variable have negligible AICc-weight and so do not appear in this table); 2, “clade” covariate comparing titanosaurians to non-titanosaurians; 3, comparison that does not include phylogenetic regression models, therefore allowing increased sample size to test the hypothesis of titanosaurian femoral eccentricity; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The strong, non-phylogenetic relationships of FC with FML and HC in sauropods allow us to estimate missing values of FC based on the complete sets of N = 45 (FML; R2 = 0.984) and N = 37 (HC; R2 = 0.950) taxa in which the relevant measurements were known. This resulted in equations [19] and [20]. When AICc weights are compared over the set of N = 17 taxa for which FC and both FML and HC are known, models including FML have a combined AICc-weight > 0.99, showing that FML is the best estimator of FC in quadrupedal sauropodomorphs. Equation [19] allows 42 estimates of missing FC values in sauropodmorphs for which FML is known. Equation [20] allows 12 estimates of FC in sauropodmorphs for which HC is known. These relationships were used in preference to those for quadrupedal Dinosauria (i.e. equations [15] and [16] above) when their prediction errors were lower.

[19] log10(FC) = 0.961 \* log10(FML) + 0.508

[20] log10(FC) = 1.014 \* log10(HC) + 0.049

Humeral circumference in quadrupedal sauropodomorphs is predicted well by non-phylogenetic relationships with HML and FC (Table S6). Other measurements, such as HL, HAP, FL, RC, and RL have weaker relationships with HC (R2 < 0.90; Table S6). When models including HML and FC as predictors of HC are compared over the set of N = 21 taxa for which all three variables are known, the best model including FC has a slightly better AICc-weight (= 0.51) than the best model including HML (AICc-weight = 0.24). This suggests that FC provides only slight better estimates of HC in quadrupedal sauropodomorphs.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | HC ~ HML + intercept | 0.89 | 29 | 0.914 | 0.678 | 0.891 | <0.001 | 0.00 |
| 2 | HC ~ HML + intercept + clade2 | 0.03 | 29 | 0.900\* | 0.682 | 0.890 | <0.001 | 0.00 |
| 3 | HC ~ HML + clade2 | 0.03 | 29 | 0.900\* | - | 0.890 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HAP + intercept | 0.39 | 17 | 0.717 | 1.172 | 0.731 | <0.001 | 1.00 |
| 2 | HC ~ HAP + intercept | 0.34 | 17 | 0.795 | 0.941 | 0.847 | <0.001 | 0.00 |
| 3 | HC ~ HAP + intercept | 0.17 | 17 | 0.686 | 1.201 | 0.721 | <0.001 | 1.04 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HL + intercept | 0.31 | 39 | 0.698 | 0.454 | 0.732 | <0.001 | 0.00 |
| 2 | HC ~ HL + intercept | 0.30 | 39 | 0.710 | 0.435 | 0.741 | <0.001 | -0.06 |
| 3 | HC ~ HL | 0.21 | 39 | 0.674 | - | 0.883 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FC | 0.88 | 30 | 0.933 | - | 0.969 | <0.001 | 0.00 |
| 2 | HC ~ FC + intercept | 0.09 | 30 | 0.928 | 0.052 | 0.950 | <0.001 | 0.00 |
| 3 | HC ~ FC | 0.02 | 30 | 0.921 | - | 0.969 | <0.001 | -0.06 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FL | 0.76 | 25 | 0.862 | - | 0.857 | <0.001 | -0.33 |
| 2 | HC ~ FL | 0.12 | 25 | 0.843 | - | 0.851 | <0.001 | 0.00 |
| 3 | HC ~ FL | 0.07 | 25 | 0.847 | 0.069 | 0.832 | <0.001 | 0.06 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RC | 0.58 | 10 | 0.900 | - | 1.098 | <0.001 | 0.00 |
| 2 | HC ~ RC | 0.16 | 10 | 0.722 | - | 1.101 | <0.001 | 1.00 |
| 3 | HC ~ RC | 0.10 | 10 | -0.107 | - | 1.099 | <0.001 | 0.40 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RL + intercept | 0.37 | 23 | 0.626 | 0.811 | 0.660 | <0.001 | -0.11 |
| 2 | HC ~ RL + intercept | 0.27 | 23 | 0.746 | 0.670 | 0.708 | <0.001 | 0.00 |
| 3 | HC ~ RL + intercept | 0.25 | 23 | 0.594 | 1.063 | 0.557 | <0.001 | 1.00 |

**Table S6.** Best regression models (based on AICc-weight) to predict log10(HC) from log10(HAP), log10(HL), log10(FC), log10(FL), log10(RC) and log10(RL) in quadrupedal sauropodomorphs. Abbreviations and notes: 2, “clade” covariate comparing titanosaurians to non-titanosaurians; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The strong, non-phylogenetic relationships of HC with HML and FC allow us to predict missing values of HC based on the complete set of N = 37 (FC; R2 > 0.999) or N = 43 (HML; R2 = 0.946) taxa in which the relevant variables are known, resulting in equations [21] and [22] below. These equations allow 30 additional estimates of HC based on FC in taxa for which HCoval is not known, and 44 estimates of HC based on HML for taxa in which neither HCoval or FC are known.

[21] log10(HC) = 0.969 \* log10(FC)

[22] log10(HC) = 0.900 \* log10(HML) + 0.667

**Thyreophora.** Femoral shaft circumferences (FC) in thyreophoran dinosaurs have a strong relationship with both FML and HC. The relationship with HC is not dependent on phylogeny, and including phylogenetic signal, or clade (Stegosauria | Ankylosauria) as a covariate does not improve the model (Table S7). However, the relationship with FML includes a strong phylogenetic signal (λ = 1.00 or 0.98), indicating that the eccentricity of the femur varies not only between Stegosauria and Ankylosauria, but also among closely-related taxa in our phylogeny. When models including HC and FML as predictors of FC are compared based on the set of N = 6 taxa in which all three measurements are known, models including HC have a combined AICc-weight of 0.89, indicating that HC is a better predictor of FC than is FML. Other measurements, such as FL, FAP, HL, TL and TC have weaker relationships with FC (R2 < 0.81; Table S7).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept | 0.60 | 13 | 0.922 | 0.474 | 0.973 | <0.001 | 1.00 |
| 2 | FC ~ FML + intercept | 0.23 | 13 | 0.913 | 0.475 | 0.972 | <0.001 | 0.98 |
| 3 | FC ~ FML + intercept | 0.07 | 13 | 0.920 | 0.661 | 0.886 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FL | 0.32 | 20 | 0.804 | - | 0.875 | <0.001 | 0.83 |
| 2 | FC ~ FL | 0.14 | 20 | 0.766 | - | 0.875 | <0.001 | 1.00 |
| 3\*\* | FC ~ FL + clade1 + intercept | 0.10\* | 20 | 0.830 | -0.507 | 1.069 | <0.001 | 0.73 |
| 4\*\* | FC ~ FL + clade1 + intercept | 0.10\* | 20 | 0.830 | - | 1.069 | <0.001 | 0.73 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP + intercept | 0.55 | 12 | 0.693 | 0.735 | 0.942 | <0.001 | 0.00 |
| 2 | FC ~ FAP | 0.23 | 12 | 0.545 | - | 1.354 | <0.001 | 0.00 |
| 3 | FC ~ FAP | 0.10 | 12 | 0.436 | - | 1.354 | <0.001 | -0.22 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HC | 0.85 | 11 | 0.951 | - | 1.025 | <0.001 | 0.00 |
| 2 | FC ~ HC + intercept | 0.06 | 11 | 0.940 | 0.007 | 1.022 | <0.001 | 0.00 |
| 3 | FC ~ HC + intercept | 0.04 | 11 | 0.959 | 0.374 | 0.871 | <0.001 | -1.05 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HL | 0.74 | 10 | 0.604 | - | 0.916 | <0.001 | 0.00 |
| 2 | FC ~ HL + intercept | 0.20 | 10 | 0.626 | -0.031 | 0.928 | <0.001 | 0.00 |
| 3 | FC ~ HL + clade1 + intercept | 0.01 | 10 | 0.432 | - | 0.909 | <0.001 | -0.25 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TL | 0.45 | 8 | 0.689 | - | 0.886 | <0.001 | 1.31 |
| 2 | FC ~ TL | 0.37 | 8 | 0.619 | - | 0.926 | <0.001 | 0.00 |
| 3 | FC ~ TL + intercept | 0.09 | 8 | 0.663 | 0.391 | 0.776 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.30 | 7 | 0.028 | - | 1.045 | <0.001 | 0.00 |
| 2 | FC ~ intercept | 0.27 | 7 | 0.000 | 2.383 | - | - | 0.00 |
| 3 | FC ~ TC + intercept | 0.13 | 7 | 0.322 | 0.852 | 0.672 | 0.672 | 0.00 |

**Table S7.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FL), log10(FAP), log10(HC), log10(HL), log10(TL) and log10(TC) in thyreophoran ornithischians. Abbreviations and notes: 1, comparisons including “clade” as a categorical covariate denoting assignment to Ankylosauria or Stegosauria; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The strong relationships of FC with HC and FML allow us to predict FC using the non-phylogenetic relationship of FC with HC (equation [23], based on the complete set of N = 11 thyreophoran specimens for which FC and HC are both known, regardless of whether they are included in our phylogeny) and the phylogenetic relationship of FML with FC (equation [24]; Table S7). Equation [24] does not allow any additional estimates of FC in taxa for which the data were not already available.

[23] log10(FC) = 1.025 \* log10(HC)

[24] log10(FC) = 0.973 \* log10(FML) + 0.474 [λ = 1.00]

A non-phylogenetic relationship with FC provides the best estimate of HC for thyreophorans, better than the relationships with humeral measurements (Table S8), which have R2 < 0.87. The non-phylogenetic relationship between FC and HC based on the complete set of N = 11 is given in equation [25], and allows seven additional estimates of HC from FC, and two additional estimates of HC from FC (using the well-constrained relationship between FC and FCoval).

[25] log10(HC) = 0.975 \* log10(FC)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | HC ~ HML + intercept | 0.89 | 13 | 0.866 | 0.669 | 0.892 | <0.001 | 0.00 |
| 2\*\* | HC ~ HML + intercept + clade1 | 0.04 | 13 | 0.831 | 0.780 | 0.828 | <0.001 | 0.00 |
| 3\*\* | HC ~ HML + clade1 | 0.04 | 13 | 0.831 | - | 0.828 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HAP + intercept | 0.72 | 11 | 0.678 | 0.875 | 0.840 | <0.001 | 0.00 |
| 2 | HC ~ HAP | 0.13 | 11 | 0.417 | - | 1.323 | <0.001 | 0.00 |
| 3 | HC ~ HAP + intercept | 0.03 | 11 | 0.244 | 1.755 | 0.389 | 0.040 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HL | 0.75 | 16 | 0.706 | - | 0.891 | <0.001 | 0.00 |
| 2 | HC ~ HL + intercept | 0.18 | 16 | 0.701 | 0.123 | 0.844 | <0.001 | 0.00 |
| 3 | HC ~ HL | 0.03 | 16 | 0.751 | - | 0.890 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FC | 0.87 | 11 | 0.949 | - | 0.976 | <0.001 | 0.00 |
| 2 | HC ~ FC + intercept | 0.07 | 11 | 0.939 | 0.066 | 0.949 | <0.001 | 0.00 |
| 3 | HC ~ FC | 0.02 | 11 | 0.948 | - | 0.970 | <0.001 | 0.19 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FL | 0.66 | 12 | 0.750 | - | 0.840 | <0.001 | 0.00 |
| 2 | HC ~ FL + intercept | 0.24 | 12 | 0.768 | 0.356 | 0.715 | <0.001 | 0.00 |
| 3 | HC ~ FL + clade1 + intercept | 0.02 | 12 | 0.827 | -0.702 | 1.135 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ intercept | 0.34 | 6 | 0.000 | 2.356 | - | <0.001 | 0.00 |
| 2 | HC ~ intercept | 0.15 | 6 | 0.000 | 2.471 | - | <0.001 | 1.00 |
| 3 | HC ~ RL | 0.15 | 6 | -0.003 | - | 0.932 | - | 1.00 |

**Table S8.** Best regression models (based on AICc-weight) to predict log10(HC) from log10(HML), log10(HAP), log10(HL), log10(FC), log10(FL) and log10(RL) in thyreophoran ornithischians. Measured values of RC and HC are not present together in any thyreophoran in our dataset. Abbreviations and notes: 1, comparisons including “clade” as a categorical covariate denoting assignment to Ankylosauria or Stegosauria; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

**Quadrupedal Ceratopsia.** Measurements of the femur (FML, FL, FAP) and tibia (TL, TC) do a very poor job of predicting FC (R2 < 0.85; Table S9) in quadrupedal ceratopsians, and so were not used. However, FC has a strong, non-phylogenetic relationship with both HC (R2 = 0.97) and HL (R2 = 0.96) (Table S9). When models are compared over the set of N = 5 taxa for which FC, HC, and HL are all known, models including HC have a combined AICc-weight of 0.97, indicating that HC is the best predictor of FC in quadrupedal ceratopsians.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept | 0.48 | 8 | 0.830 | 0.868 | 0.784 | <0.001 | 1.00 |
| 2 | FC ~ FML + intercept | 0.27 | 8 | 0.914 | 0.724 | 0.870 | <0.001 | 0.00 |
| 3 | FC ~ FML + intercept | 0.20 | 8 | 0.820 | 0.854 | 0.789 | <0.001 | 0.93 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FL | 0.47 | 13 | 0.765 | - | 0.872 | <0.001 | 1.00 |
| 2 | FC ~ FL | 0.18 | 13 | 0.880 | - | 0.873 | <0.001 | 0.00 |
| 3 | FC ~ FL | 0.17 | 13 | 0.707 | - | 0.872 | <0.001 | 1.00 |
| 4 | FC ~ FL + intercept | 0.11 | 13 | 0.764 | -0.181 | 0.939 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP | 0.33 | 7 | 0.803 | - | 1.297 | <0.001 | 0.00 |
| 2 | FC ~ FAP + intercept | 0.30 | 7 | 0.890 | 0.522 | 1.015 | <0.001 | 0.00 |
| 3 | FC ~ FAP + intercept | 0.13 | 7 | 0.748 | 0.526 | 1.015 | <0.001 | -0.39 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HC + intercept | 0.75 | 11 | 0.965 | 0.332 | 0.909 | <0.001 | 0.00 |
| 2 | FC ~ HC | 0.15 | 11 | 0.938 | - | 1.051 | <0.001 | 0.00 |
| 3 | FC ~ HC | 0.06 | 11 | 0.825 | - | 1.059 | <0.001 | 0.52 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HL + intercept | 0.54 | 11 | 0.963 | -0.952 | 1.259 | <0.001 | 0.00 |
| 2 | FC ~ HL + intercept | 0.21 | 11 | 0.876 | -1.031 | 1.295 | <0.001 | 1.00 |
| 3 | FC ~ HL + intercept | 0.19 | 11 | 0.870 | -0.957 | 1.262 | <0.001 | 0.41 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TL | 0.46 | 10 | 0.588 | - | 0.894 | <0.001 | 1.00 |
| 2 | FC ~ TL | 0.20 | 10 | 0.596 | - | 0.897 | <0.001 | 1.04 |
| 3 | FC ~ TL + intercept | 0.19 | 10 | 0.644 | -0.483 | 1.080 | 0.002 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.56 | 5 | 0.670 | - | 1.001 | <0.001 | 1.00 |
| 2 | FC ~ TC | 0.17 | 5 | 0.772 | - | 1.007 | <0.001 | 0.00 |
| 3 | FC ~ TC | 0.14 | 5 | -0.217 | - | 0.991 | <0.001 | 1.97 |

**Table S9.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FAP), log10(HC), log10(HL), log10(TL) and log10(TC) in quadrupedal ceratopsians. Abbreviations and notes: N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The relationships of FC with HC and HL, based on the complete set of N = 12 (HC; R2 > 0.999) or N = 12 (HL) specimens for which the relevant measurements are known is given in equations [26] and [27] below. These relationships allow zero (HC) and six (HL) additional estimates of FC for taxa in which FC and FCoval are unknown.

[26] log10(FC) = 0.907 \* log10(HC) + 0.336

[27] log10(FC) = 1.261 \* log10(HL) - 0.957

Humeral circumference (HC) has a strong, non-phylogenetic relationship with HL and FC in quadrupedal ceratopsians (Table S10). When models in which HC is explained by HL or FC are compared over the set of N = 10 taxa for which these measurements are available, models including FC have a combined AICc-weight of 0.95, indicating that FC is the best predictor of HC.

Strong, non-phylogenetic relationships between HC and measurements of the radius (RC, RL) have comparable AICc-weight to models including phylogenetic signal, and with lower explanatory power (R2<0.70; Table S10). This raises the possibility that phylogeny, rather than a functional scaling relationship, drives the relationship between HC and radial measurements observed in the small sample of taxa for which these can be compared. Therefore, we do not use radial measurements to predict HC in quadrupedal ceratopsians.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | HC ~ HML | 0.38 | 5 | 0.605 | - | 1.251 | <0.001 | 1.00 |
| 2 | HC ~ HML | 0.14 | 5 | 0.271 | - | 1.251 | <0.001 | 1.01 |
| 3 | HC ~ HML + intercept | 0.12 | 5 | 0.836 | 0.687 | 0.878 | 0.006 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HAP + intercept | 0.59 | 4 | 0.818 | - | 1.322 | <0.001 | 1.00 |
| 2 | HC ~ HAP | 0.18 | 4 | 0.852 | - | 1.320 | <0.001 | 0.00 |
| 3 | HC ~ HAP + intercept | 0.13 | 4 | 0.660 | - | 1.337 | <0.001 | 1.33 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HL + intercept | 0.62 | 10 | 0.955 | -1.364 | 1.368 | <0.001 | 0.00 |
| 2 | HC ~ HL + intercept | 0.19 | 10 | 0.873 | -1.344 | 1.360 | <0.001 | 0.12 |
| 3 | HC ~ HL + intercept | 0.15 | 10 | 0.850 | -1.224 | 1.317 | 0.014 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FC + intercept | 0.40 | 11 | 0.966 | -0.323 | 1.082 | <0.001 | 0.00 |
| 2 | HC ~ FC | 0.26 | 11 | 0.951 | - | 0.951 | <0.001 | 0.00 |
| 3 | HC ~ FC + intercept | 0.18 | 11 | 0.919 | -0.345 | 0.919 | <0.001 | -0.22 |
| 4 | HC ~ FC | 0.11 | 11 | 0.883 | - | 0.883 | <0.001 | 0.53 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FL | 0.28 | 11 | 0.656 | - | 0.804 | <0.001 | 1.07 |
| 2 | HC ~ FL | 0.23 | 11 | 0.827 | - | 0.830 | <0.001 | 0.00 |
| 3 | HC ~ FL | 0.16 | 11 | 0.624 | - | 0.832 | <0.001 | 1.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RC | 0.43 | 4 | 0.909 | - | 1.149 | <0.001 | 0.00 |
| 2 | HC ~ RC | 0.27 | 4 | 0.694 | - | 1.141 | <0.001 | 1.00 |
| 3 | HC ~ RC | 0.23 | 4 | 0.634 | - | 1.145 | <0.001 | 0.63 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RL + intercept | 0.32 | 7 | 0.926 | -1.102 | 1.379 | <0.001 | 0.00 |
| 2 | HC ~ RL + intercept | 0.32 | 7 | 0.875 | -1.363 | 1.493 | <0.001 | -7.04 |
| 3 | HC ~ RL | 0.16 | 7 | 0.679 | - | 0.922 | <0.001 | 1.00 |

**Table S10.** Best regression models (based on AICc-weight) to predict log10(HC) from log10(HML), log10(HAP), log10(HL), log10(FC), log10(FL), log10(RC) and log10(RL) in quadrupedal ceratopsians. Abbreviations and notes: N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The non-phylogenetic relationships of HC with FC and HL, based on the complete set of N = 12 (FC; R2 = 0.983) or N = 12 (HL; R2 = 0.969) specimens for which the relevant measurements are known are given in equations [28] and [29]. These measurements allow one additional estimate of HC using FC, and five additional estimates of HC using HL, in taxa for which HC and HCoval are not known.

[28] log10(HC) = 1.086 \* log10(FC) - 0.330

[29] log10(HC) = 1.415 \* log10(HL) - 1.482

**Quadrupedal Iguanodontia.** Femoral measurements provide good estimates of FC in quadrupedal iguanodontians, whereas measurements of the humerus and tibia provide poor estimates (Table S11). The relationship of FC with FML contains no phylogenetic signal, and adding phylogenetic signal or a covariate specifying assignment to Hadrosauroidea or non-Hadrosauroidea does not improve the best model, although a model including “clade” has a non-negligible AICc-weight (Table S11). The best model of the relationship between FC and FL includes “clade” as a covariate, indicating that hadrosauroids have a different scaling relationship to other iguanodontians. The best model of the relationship between FC and FAP contains a weak phylogenetic signal (λ = 0.20). Nevertheless, we prefer to use the non-phylogenetic relationship, which has a non-negligible AICc-weight, and allows a larger number of estimates to be made because taxa need not be included in our phylogeny to have measurements estimated using non-phylogenetic approaches. When models explaining FC in terms of either FL, FML or FAP are compared over the set of N = 25 iguanodontians for which all four measurements are known, models including FL have a combined AICc-weight > 0.99, indicating that FL provides the best predictions of FC in quadrupedal iguanodontians. AICc weights also indicate that FAP provides better predictions of FC than does FML.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | FC ~ FML + intercept | 0.66 | 25 | 0.930 | 0.590 | 0.955 | <0.001 | 0.00 |
| 2\*\* | FC ~ FML + clade1 + intercept | 0.14 | 25 | 0.928 | 0.755 | 0.884 | <0.001 | 0.00 |
| 3\*\* | FC ~ FML + clade1 | 0.14 | 25 | 0.928 | - | 0.884 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1\*\* | FC ~ FL + clade1 + intercept | 0.26\* | 39 | 0.965 | -0.699 | 1.095 | <0.001 | 0.00 |
| 2\*\* | FC ~ FL + clade1 | 0.26\* | 39 | 0.965 | - | 1.095 | <0.001 | 0.00 |
| 3 | FC ~ FL + intercept | 0.20 | 39 | 0.963 | -0.420 | 1.006 | <0.001 | 0.00 |
| 4\*\* | FC ~ FL \* clade1 + intercept | 0.08\* | 39 | 0.966 | -0.347 | 0.978 | <0.001 | 0.00 |
| 4\*\* | FC ~ FL \* clade1 | 0.08\* | 39 | 0.966 | - | 0.978 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ FAP + intercept | 0.66 | 27 | 0.874 | 0.668 | 0.930 | <0.001 | 0.20 |
| 2 | FC ~ FAP + intercept | 0.19 | 27 | 0.941 | 0.679 | 0.935 | <0.001 | 0.00 |
| 3 | FC ~ FAP + clade1 + intercept | 0.03 | 27 | 0.945 | 1.145 | 0.710 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HC | 0.26 | 21 | 0.758 | - | 1.105 | <0.001 | 0.00 |
| 2 | FC ~ HC + intercept | 0.20 | 21 | 0.567 | 0.631 | 0.826 | <0.001 | 0.79 |
| 3 | FC ~ HC | 0.13 | 21 | 0.492 | - | 1.106 | <0.001 | 0.62 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ HL | 0.49 | 20 | 0.525 | - | 0.934 | <0.001 | 0.49 |
| 2 | FC ~ HL | 0.19 | 20 | 0.753 | - | 0.942 | <0.001 | 0.00 |
| 3 | FC ~ HL + intercept | 0.13 | 20 | 0.520 | -0.073 | 0.961 | <0.001 | 0.49 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TL | 0.59 | 19 | 0.598 | - | 0.878 | <0.001 | 0.00 |
| 2 | FC ~ TL + intercept | 0.20 | 19 | 0.606 | 0.247 | 0.794 | <0.001 | 0.00 |
| 3 | FC ~ TL | 0.11 | 19 | 0.479 | - | 0.889 | <0.001 | 0.37 |
|  |  |  |  |  |  |  |  |  |
| 1 | FC ~ TC | 0.68 | 14 | 0.691 | - | 1.031 | <0.001 | 0.00 |
| 2 | FC ~ TC + intercept | 0.29 | 14 | 0.713 | 0.397 | 0.973 | <0.001 | 0.00 |
| 3 | FC ~ TC + intercept | 0.01 | 14 | 0.317 | 1.167 | 0.556 | 0.014 | 1.00 |

**Table S11.** Best regression models (based on AICc-weight) to predict log10(FC) from log10(FML), log10(FL), log10(FAP), log10(HC), log10(HL), log10(TL) and log10(TC) in quadrupedal iguanodontians. Abbreviations and notes: 1, “clade” covariate specifying assignment to either Hadrosauroidea or non-Hadrosauroidea; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The non-phylogenetic relationship between FC and FL, including “clade” (non-hadrosauroid|hadrosauroid) as a covariate, based on the complete set of N = 41 taxa for which both FC and FL are known is given in equation [31] below (R2 < 0.999). The non-phylogenetic relationships of FC with FAP and FML based on the complete set of N = 27 (FAP; R2 = 0.954) and N = 25 (FML; R2 = 0.945) specimens in which the relevant measurements were known are given in equations [31] and [32]. These measurements allow 18 additional estimates of FC using FL for iguanodontians in which FC and FCoval are not known, one further estimate using FAP when FL is also not known, and zero further estimates using FML.

[30] log10(FC) = 1.109 \* log10(FL) - 0.672 in non-Hadrosauroidea

log10(FC) = 1.109 \* log10(FL) - 0.740 in Hadrosauroidea

[31] log10(FC) = 0.935 \* log10(FAP) + 0.679

[32] log10(FC) = 0.956 \* log10(FML) + 0.590

Humeral shaft circumference has a strong relationship with HL, HML and HAP in quadrupedal iguanodontians. By contrast, measurements of the femur and radius have only weak relationships with HC (Table S12). The relationships of HC with HML and HL are non-phylogenetic, although models including “clade” (non-hadrosauroid|hadrosauroid) as an interaction term have non-negligible AICc weights in the comparison of HC and HL, and models including strong phylogenetic signal have comparable weights to non-phylogenetic models in the comparison of HC to HAP. When models explaining HC in terms of either HL, HML or HAP are compared across the set of N = 15 taxa in which all four measurements are known, the combined AICc-weight of models including HML > 0.99, indicating that HML is the best predictor of HC. AICc weights also indicate that HAP is a better predictor of HC than is HL in quadrupedal iguanodontians.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Rank** | **Model** | **AICc-weight** | **N** | **R2** | **Intercept** | **slope** | **p-value** | **λ** |
| 1 | HC ~ HML + intercept | 0.48 | 16 | 0.966 | 0.580 | 0.946 | <0.001 | 0.00 |
| 2 | HC ~ HML + intercept | 0.44 | 16 | 0.951 | 0.541 | 0.966 | <0.001 | 0.01 |
| 3 | HC ~ HML + clade1 | 0.02 | 16 | 0.940 | - | 0.924 | <0.001 | -0.35 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HAP + intercept | 0.37 | 15 | 0.942 | 0.574 | 0.997 | <0.001 | 0.00 |
| 2 | HC ~ HAP + intercept | 0.32 | 15 | 0.899 | 0.650 | 0.933 | <0.001 | 1.00 |
| 3 | HC ~ HAP + intercept | 0.18 | 15 | 0.899 | 0.598 | 0.964 | <0.001 | 0.96 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ HL + intercept | 0.54 | 29 | 0.933 | -0.609 | 1.077 | <0.001 | 0.00 |
| 2\*\* | HC ~ HL \* clade1 + intercept | 0.10 | 29 | 0.938 | 0.069 | 0.833 | <0.001 | 0.00 |
| 3\*\* | HC ~ HL \* clade1 + intercept | 0.10 | 29 | 0.938 | - | 0.833 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FC | 0.47 | 21 | 0.760 | - | 0.904 | <0.001 | 0.00 |
| 2 | HC ~ FC | 0.24 | 21 | 0.526 | - | 0.901 | <0.001 | 0.63 |
| 3 | HC ~ FC + intercept | 0.13 | 21 | 0.758 | 0.219 | 0.819 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ FL | 0.32 | 21 | 0.746 | - | 0.780 | <0.001 | 0.00 |
| 2\*\* | HC ~ FL + clade1 + intercept | 0.15\* | 21 | 0.788 | -1.056 | 1.125 | <0.001 | 0.00 |
| 3\*\* | HC ~ FL + clade1 | 0.15\* | 21 | 0.788 | - | 1.125 | <0.001 | 0.00 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RC | 0.33 | 10 | 0.851 | - | 1.102 | <0.001 | 0.00 |
| 2 | HC ~ RC + intercept | 0.29 | 10 | 0.889 | 0.410 | 0.911 | <0.001 | 0.00 |
| 3 | HC ~ RC + intercept | 0.20 | 10 | 0.902 | 0.531 | 0.854 | <0.001 | -0.17 |
|  |  |  |  |  |  |  |  |  |
| 1 | HC ~ RL + intercept | 0.16 | 16 | 0.000 | 2.331 | - | - | 1.00 |
| 2 | HC ~ RL + intercept | 0.15 | 16 | 0.309 | 1.265 | 0.402 | 0.006 | 0.00 |
| 3 | HC ~ RL | 0.11 | 16 | 0.208 | 1.223 | 0.410 | 0.001 | 0.26 |

**Table S12.** Best regression models (based on AICc-weight) to predict log10(HC) from log10(HML), log10(HAP), log10(HL), log10(FC), log10(FL), log10(RC) and log10(RL) in quadrupedal iguanodontians. Abbreviations and notes: 1, “clade” covariate specifying assignment to either Hadrosauroidea or non-Hadrosauroidea; N, sample size; R2, generalised coefficient of determination calculated using the formula of Nagelkerke (1991); λ, lambda phylogenetic signal parameter (Pagel 1999); \*\*, denotes mathematically equivalent, identical models. Only models with non-negligible AICc weights (and minimally the best three models) are shown. See text for information about the full set of models compared. Because phylogenetic and non-phylogenetic models were compared, results reported in this table use only the set of taxa for which the required variables were known, and which were included in our phylogeny.

The non-phylogenetic relationships of HC with HML, HAP and HML, based on the complete sets of N = 16 (HML; R2 = 0.98), N = 15 (HAP; R2 = 0.96) and N = 31 (HL; R2 = 0.947) specimens in which the relevant measurements are known are given in equations [33], [34] and [35] below. These equations allow five additional measurements using the relationship between HC and HML in taxa for which HC and HCoval were not known, five further measurements using the relationship between HC and HAP, and a further eight measurements using the relationship between HC and HL in taxa for which HC, HCoval, HML and HAP were not known.

[33] log10(HC) = 0.946 \* log10(HML) + 0.580

[34] log10(HC) = 0.997 \* log10(HAP) + 0.574

[35] log10(HC) = 1.081 \* log10(HL) - 0.617

**References**

Benson RBJ *et al*. (2014) Rates of dinosaur body mass evolution indicate 170 million years of sustained ecological innovation on the avian stem lineage. PLoS Biol 12(5): 1001853 (doi:10.1371/journal.pbio.1001853).

Bonaparte JF, Pumares JA. 1995. Notas sobre el primer craneo de *Riojasaurus incertus* (Dinosauria, Prosauropoda, Melanorosauridae) del Triasico Superios de La Rioja, Argentina. Ameghiniana 32: 341-349.

Bonnan MF. 2003. The evolution of manus shape in sauropod dinosaurs: implications for functional morphology, forelimb orientation, and phylogeny. Journal of Vertebrate Paleontology 23, 595-613.

Burnham KP, Anderson DR (2004) Model selection and multimodel inference. New York: Springer. 488 p.

Campione NE, Evans DC (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biol 10: 1–21. doi: 10.1186/1741-7007-10-60

Campione NE, Evans DC, Brown CM, Carrano MT (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadrupedal stylopodial proportions. Method Ecol Evol (doi:10.1111/2041-210X.12226).

Chinnery B. 2004,. Morphometric analysis of evolutionary trends in the ceratopsian postcranial skeleton. Journal of Vertebrate Paleontology 24, 591-609.

Chinnery B, Horner JR. 2007. A new neoceratopsian dinosaur linking North American and Asian taxa. Journal of Vertebrate Paleontology 27, 625-641. doi: 10.1671/0272-4634(2007)27[625:ANNDLN]2.0.CO;2

Garland T Jr, Ives AR (2001) Using the past to predict the present: confidence intervals for regression equations in phylogenetic comparative methods. Am Nat 155:346-364.

Lacovara, KJ, Ibiricu LM, Lamanna MC, Poole JC, Schroeter ER, Ullmann PV, Voegele KK, Boles ZM, Egerton VM, Harris JD, Martínez RD, Novas FE (2014). A gigantic, exceptionally complete titanosaurian sauropod dinosaur from southern Patagonia, Argentina". Scientific Reports 4, 6196. doi:10.1038/srep06196.

Lamanna MC, Sues H-D, Schachner ER, Lyson TR. 2014. A new large-bodied oviraptorosaurian theropod from the latest Cretaceous of western North America. PLOS ONE 9(3), e902022. doi:10.1371/journal.pone.0092022.

Lee Y-N, Barsbold R, Currie PJ, Kobayashi Y, Lee H-J, Godefroit P, Escuillié F, Chinzorig T. 2014. Resolving the long-standing enigmas of a giant ornithomimosaur *Deinocheirus mirificus*. Nature 515, 257-260.

Maidment SCR, Linton DH, Upchurch P, Barrett PM. 2012. Limb-bone scaling indicates diverse stance and gait in quadrupedal ornithischian dinosaurs. PLOS One 7, e36904.

Maidment SCR, Barrett PM. 2012. Osteological correlates for quadrupedality in ornithischian dinosaurs. Acata Palaeontologica Polonica 59, 53–70.

Nagelkerke NJD. 1991. A note on the general definition of the coefficient of determination. Biometrika 78, 691–692.

Norman DB. 1980. On the ornithischian dinosaur Iguanodon bernissatensis from the Lower Cretaceous of Bernissart (Belgium). Mémoires de l'Institut Royal des Sciences Naturelles de Belgique 178, 1–103.

Norman DB. 1986. On the anatomy of Iguanodon atherfieldensis (Ornithischia: Ornithopoda). Bulletin de l'Institut Royal des Sciences Naturelle de Belgique: Sciences de la Terre 56, 281–372.

Pagel M (1999) Inferring the historical patterns of biological evolution. Nature 401: 877–884. doi: 10.1038/44766

Paradis E, Claude J, Strimmer K. 2004. APE: analyses of phylogenetics and evolution in R language. Bioinformatics 20: 289-290.

Pinheiro J, Bates D, DebRoy S, Sarkar D and R Core Team (2014). \_nlme: Linear and Nonlinear Mixed Effects Models\_. R package version 3.1-117, <URL: http://CRAN.R-project.org/package=nlme>.

Sugiura N (1978) Further analysis of the data by Akaike's information criterion and the finite corrections. Commun Statist—Theor Meth 7: 13–26.

Wilson JA, Carrano MT. 1999. Titanosaurs and the origin of “wide-gauge” trackways: a biomechanical and systematic perspective on sauropod locomotions. Paleobiology 25, 252–267.

Yates AM. 2007 The first complete skull of the Triassic dinosaur *Melanorosaurus* Haughton (Sauropodomorpha: Anchisauria). Spec. Papers Palaeontol. 77, 9–55

Yates AM, Kitching JW. 2003. The earliest known sauropod dinosaur and the first steps towards sauropod locomotion. Proceedings of the Royal Society of London B: Biological Sciences 270: 1753-1758.

Yates AM, Bonnan MF, Neveling J, Chinsamy A, Blackbeard MG. 2010. A new transitional sauropodomorph dinosaur from the Early Jurassic of South Africa and the evolution of sauropod feeding and quadrupedalism. Proceedings of the Royal Society B 277, 787–794. doi: 10.1098/rspb.2009.1440

Zhao Q, Benton MJ, Sullivan C, Sander PM, Xu X. 2013. Histology and postural change during the growth of the ceratopsian dinosaur *Psittacosaurus lujiatunensis*. Nature Communications 4, 2079. doi:10.1038/ncomms3079.