**Supplementary material**

Table S1

List of all birds, the length of bones they contributed, the source museum and accession number, and body mass. YPM, Yale Peabody Museum; UMZC, University Museum of Zoology, Cambridge; RVC, The Royal Veterinary College; IC, Imperial College, London. \* denotes known body mass, other body masses are estimates from literature.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Museum** | **Accession** | **Order** | **Family** | **Binomial name** | **Familiar name** | ***M*b (kg)** | **Femur (mm)** | **Tibiotarsus (mm)** | **Tarsometatarsus (mm)** | **Gait** |
| YPM | 1797 | Accipitriformes | Sagittariidae | *Sagittarius serpentarius* | secretary bird | 4.01 | 113.18 | - | - | flying |
| YPM | 14510 | Accipitriformes | Sagittariidae | *Sagittarius serpentarius* | secretary bird | 4.01 | 109.94 | - | - | flying |
| UMZC | 222.a | Anseriformes | Anatidae | *Anas superciliosa* | Pacific black duck | 1 | 53.61 | 89.81 | 46.7 | dabbling |
| UMZC | 242.E | Anseriformes | Anatidae | *Anser albifrons* | greater white-fronted goose | 2.21 | 65.2 | 113 | 65.84 | dabbling |
| UMZC | 246.F | Anseriformes | Anatidae | *Branta bernicla* | brent goose | 1.34 | 62.63 | 117.87 | 67.28 | dabbling |
| UMZC | 242.AA | Anseriformes | Anatidae | *Cereopsis novaehollandiae* | Cape Barren goose | 4.4 | 92.14 | - | - | dabbling |
| UMZC | 246.G | Anseriformes | Anatidae | *Chenonetta jubata* | Australian wood duck | 0.82 | 51.84 | 90.66 | 51 | dabbling |
| RVC | swan1 | Anseriformes | Anatidae | *Cygnus olor* | mute swan | 10.95\* | 105.45 | 211.19 | 113.57 | dabbling |
| UMZC | 704 | Anseriformes | Anatidae | *Somateria mollissima* | common eider | 2.04 | 63.71 | - | - | dabbling |
| YPM | 13486 | Apterygiformes | Apterygidae | *Apteryx australis* | tokoeka | 2.3 | 105.33 | - | - | flightless |
| UMZC | 378.S | Apterygiformes | Apterygidae | *Apteryx australis* | tokoeka | 2.79 | 109.61 | - | - | flightless |
| UMZC | 378.p | Apterygiformes | Apterygidae | *Apteryx haastii* | great spotted kiwi | 1.97 | 78.32 | - | - | flightless |
| YPM | 2118 | Apterygiformes | Apterygidae | *Apteryx owenii* | little spotted kiwi | 1.2\* | 74.11 | - | - | flightless |
| UMZC | 378.iii | Apterygiformes | Apterygidae | *Apteryx owenii* | little spotted kiwi | 1.14 | 80.26 | 110.38 | 61.77 | flightless |
| YPM | 5702 | Ciconiiformes | Ardeidae | *Bubulcus ibis* | cattle egret | 0.37 | 53.89 | - | - | flying |
| RVC | racepigeon | Columbiformes | Columbidae | *Columba livia* | domestic pigeon | 0.36\* | 44.46 | 62.9 | 34.31 | flying |
| YPM | 1154 | Columbiformes | Columbidae | *Pezophaps solitaria* | Rodrigues solitaire | 22.5 | 173.13 | - | - | flightless |
| YPM | 2064 | Columbiformes | Columbidae | *Raphus cucullatus* | dodo | 20 | 140 | - | - | flightless |
| UMZC | 429p | Cuculiformes | Cuculidae | *Geococcyx californianus* | greater roadrunner | 0.38 | 54.74 | 86.3 | 66.08 | flightless |
| YPM | 4417 | Galliformes | Cracidae | *Ortalis poliocephala* | west Mexican chacalaca | 0.76 | 71.17 | - | - | burst flight |
| YPM | 382 | Galliformes | Cracidae | *Ortalis vetula* | plain chacalaca | 0.56 | 78.2 | - | - | burst flight |
| YPM | 2103 | Galliformes | Cracidae | *Pauxi pauxi* | northern helmeted curassow | 3.15 | 106.92 | - | - | burst flight |
| YPM | 376 | Galliformes | Cracidae | *Penelope purpurascens* | crested guan | 2.1 | 87.28 | - | - | flying |
| YPM | 379 | Galliformes | Megapodiidae | *Alectura lathami* | Australian brush-turkey | 2.35 | 90.79 | - | - | burst flight |
| YPM | 2090 | Galliformes | Megapodiidae | *Megapodius cumingii* | Phillippine megapode | 0.7 | 65.2 | - | - | burst flight |
| YPM | 9472 | Galliformes | Numididae | *Guttera pucherani* | crested guineafowl | 1.15 | 85.26 | - | - | burst flight |
| YPM | 7780 | Galliformes | Numididae | *Numida meleagridis* | helmeted guineafowl | 1.3 | 88.38 | - | - | burst flight |
| RVC | guineafowl1 | Galliformes | Numididae | *Numida meleagridis* | helmeted guineafowl | 1.88\* | 97.53 | 136.68 | 88.53 | burst flight |
| YPM | 7778 | Galliformes | Phasianidae | *Afropavo congensis* | Congo peafowl | 1.25 | 88.36 | - | - | burst flight |
| YPM | 2100 | Galliformes | Phasianidae | *Argusianus argus* | great argus | 1.95 | 103.79 | - | - | burst flight |
| YPM | 14735 | Galliformes | Phasianidae | *Centrocercus urophasianus* | sage-grouse | 2.25 | 74.14 | - | - | burst flight |
| YPM | 2094 | Galliformes | Phasianidae | *Chrysolophus pictus* | golden pheasant | 0.5 | 67.36 | - | - | burst flight |
| IC | quail1 | Galliformes | Phasianidae | *Coturnix coturnix* | common quail | 0.1 | 46.45 | - | - | burst flight |
| UMZC | 405.A | Galliformes | Phasianidae | *Coturnix ypsilophora* | brown quail | 0.09 | 36.66 | 43.56 | 24.33 | burst flight |
| RVC | JungleFowl1 | Galliformes | Phasianidae | *Gallus gallus* | red junglefowl | 0.78\* | 64.63 | 83.76 | 56.06 | burst flight |
| YPM | 12705 | Galliformes | Phasianidae | *Lagopus lagopus* | willow grouse | 0.5 | 56.02 | - | - | burst flight |
| YPM | 2113 | Galliformes | Phasianidae | *Meleagris gallopavo* | wild turkey | 6.05 | 150.21 | - | - | burst flight |
| RVC | turkey1 | Galliformes | Phasianidae | *Meleagris gallopavo* | wild turkey | 3.7\* | 127.73 | 206.4 | 136.02 | burst flight |
| YPM | 6658 | Galliformes | Phasianidae | *Phasianus colchicus* | common pheasant | 1.1 | 90.89 | - | - | burst flight |
| YPM | 11600 | Galliformes | Phasianidae | *Dendragapus obscurus* | dusky grouse | 1.05 | 73.23 | - | - | burst flight |
| RVC | magpie1 | Passeriformes | Corvidae | *Pica pica* | magpie | 0.26\* | 43.44 | 70.72 | 51.01 | flying |
| UMZC | 372.a | Struthioniformes | Casuariidae | *Casuarius casuarius* | southern cassowary | 44 | 222.66 | 373.53 | 281.56 | flightless |
| YPM | 2123 | Struthioniformes | Casuariidae | *Casuarius sp.* | cassowary | 44 | 196.87 | - | - | flightless |
| RVC | emu\_1 | Struthioniformes | Casuariidae | *Dromaius novaehollandiae* | emu | 27.2\* | 225.28 | - | - | flightless |
| YPM | 2128 | Struthioniformes | Casuariidae | *Dromaius novaehollandiae* | emu | 34.2 | 228.27 | - | - | flightless |
| UMZC | 621.a,b,c | Struthioniformes | Dinornithidae | *Dinornis giganteus* | South Island giant moa | 85 | 365.39 | 792.85 | 405.71 | flightless |
| YPM | 421 | Struthioniformes | Dinornithidae | *Dinornis* sp. | giant moa | 177.77 | 317.56 | - | - | flightless |
| UMZC | 609.a,b,c,d | Struthioniformes | Dinornithidae | *Emeus crassus* | eastern moa | 60.5 | 246.42 | 451.32 | 211.27 | flightless |
| UCMP | 77416 | Struthioniformes | Dinornithidae | *Pachyornis elephantopus* | Pachyornis | 250 | 315.85 | - | - | flightless |
| UMZC | 378.g | Struthioniformes | Rheidae | *Rhea americana* | greater rhea | 23 | 232.5 | 368.53 | 345.05 | flightless |
| YPM | 6503 | Struthioniformes | Rheidae | *Rhea americana* | greater rhea | 23 | 187.65 | - | - | flightless |
| RVC | ostrich2 | Struthioniformes | Struthionidae | *Struthio camelus* | ostrich | 130\* | 340.59 | 580.72 | 521.96 | flightless |
| YPM | 2124 | Struthioniformes | Struthionidae | *Struthio camelus* | ostrich | 111 | 309.66 | - | - | flightless |
| YPM | 11564 | Tinamiformes | Tinamidae | *Crypturellus undulatus* | undulated tinamou | 0.57 | 54.81 | - | - | burst flight |
| YPM | 6706 | Tinamiformes | Tinamidae | *Eudromia elegans* | elegant crested tinamou | 0.7 | 59.42 | - | - | burst flight |
| UMZC | 404.E | Tinamiformes | Tinamidae | *Eudromia elegans* | elegant crested tinamou | 0.78 | 58.6 | 81.1 | 49.14 | burst flight |
| YPM | 2040 | Tinamiformes | Tinamidae | *Nothoprocta perdicaria* | Chilean tinamou | 0.46 | 54.16 | - | - | burst flight |

**Supplementary information**

*Phylogenetically independent contrasts analysis*

We checked the influence of phylogenetic relationships on our scaling results with a phylogenetically independent contrasts (PIC) analysis (Felsenstein, 1985; Grafen, 1989; Garland et al. 1992; Pagel, 1992). For simplicity, this analysis focused on logarithmically transformed midshaft CSA, *I*max, *J*z, *Z*max and bone length, in all cases for the femur; this assumed that other bones and locations within bones show similar levels of phylogenetic bias (or lack thereof)- to analyse all possible values would be an unreasonably massive effort. As we focused mainly on basal crown clade birds, we expected minimal phylogenetic bias and thus did not consider such effort to be justified.

We entered our data into a character-taxon matrix in Mesquite 2.72 (Maddison & Maddison, 2009). Then we built a cladogram (Fig. S1) based on recent studies (Cooper et al. 2001; Dyke & Van Tuinen, 2004; Baker et al. 2005; Hackett et al. 2008; Morgan-Richards et al. 2008; Ksepka, 2009; Phillips et al. 2010). Branch lengths were initially set to 1 and the single polytomy was assumed to be soft. Divergence times for birds are quite controversial so entering absolute time-calibrated branch lengths was not deemed feasible but we conducted a sensitivity analysis of branch length assumptions (below).

We first performed diagnostic tests for normality of the data in the Mesquite PDAP:PDTREE module (Midford et al. 2005), and found that the tip data (particularly PIC values versus their standard deviations) did not have a strong fit to the assumed phylogenetic tree. We then investigated scaling of bone dimensions versus body mass PIC values over the neornithine tree. To consider differences between a simple ordinary least-squares regression (OLS; i.e., without PIC adjustments; a “star phylogeny”) and PIC analysis with different branch length assumptions we used REGRESSIONv2 (Lavin et al. 2008) code in MATLAB software (Mathworks, Inc.; Nattick, MA, USA). The two PIC models used were generalized least squares (GLS) under our initial “speciational” model of branch lengths (all branches having lengths of 1) and a GLS analysis with branch lengths transformed following an Ornstein-Uhlenbeck model (OU; (Blomberg et al. 2003)). Following (Swartz & Middleton, 2008), we checked the Akaike Information Criterion (AIC) values for each of these models (OLS, GLS, and OU) to determine which performed the best.

We obtained quite similar results for all scaling slopes versus log body mass with OLS, GLS, and OU methods (Table S2); all scaling exponents (*b*) were identical or easily within 1 S.E. of each other regardless of branch length assumptions. OLS performed best for CSA whereas OU performed best for all four of the other dimensions; albeit with only minor differences in AIC magnitudes. This indicates a negligible influence of phylogeny overall on our scaling results, as expected. Slopes were comparable to those reported in the main paper: with body mass as the independent variable we found positive allometry of all femoral dimensions except length, which displayed negative allometry. For the eight species represented by two specimens rather than a single one, we kept the specimens in the analysis. A re-run of the analysis that randomly removed one of the redundant specimens did not produce qualitatively different results.

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Figure S1 Cladogram generated for PIC. See supplementary text for details of its construction.

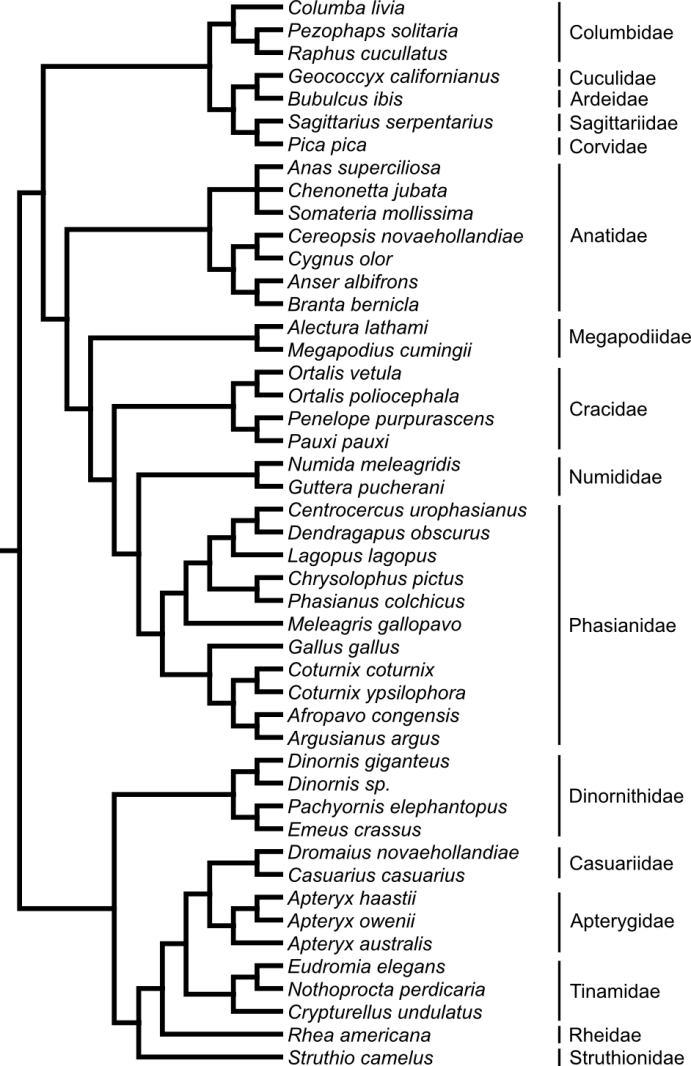


Table S2

Summary of phylogenetic independent contrasts results, where log10(*B*) ∝ *b*log10(*M*b) for birds' femora. OLS, ordinary least-squares; GLS, generalized least-squares; OU, Omstein-Uhlenbeck model; ML, maximum likelihood; AIC, Akaike Information Criterion; *se*, standard error of the mean of *b*.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ALL TAXA:** | **OLS** | | | | **GLS** | | | | **OU** | | | | |
| *B* | *b* | *se* | *ML* | *AIC* | *b* | *se* | *ML* | *AIC* | *b* | *se* | *ML* | *AIC* | *d* |
| **CSA** | 0.8260 | 0.0343 | 11.38 | **-16.76** | 0.8260 | 0.0306 | 4.33 | -2.66 | 0.8260 | 0.0330 | 11.62 | -15.24 | 0.11 |
| ***I*max** | 1.6300 | 0.0536 | -9.58 | 25.16 | 1.6290 | 0.0444 | -13.25 | 32.49 | 1.629 | 0.0484 | -8.21 | **24.41** | 0.25 |
| ***J*z** | 1.6100 | 0.0547 | -10.59 | 27.17 | 1.6100 | 0.0448 | -13.69 | 33.38 | 1.6100 | 0.0489 | -8.97 | **25.94** | 0.27 |
| ***Z*max** | 1.2100 | 0.0423 | 1.51 | 2.98 | 1.2200 | 0.0352 | -2.33 | 10.66 | 1.220 | 0.0384 | 2.82 | **2.37** | 0.27 |
| **length** | 0.2960 | 0.0130 | 56.94 | -107.87 | 0.2980 | 0.0101 | 56 | -106 | 0.2980 | 0.0111 | 59.64 | **-111.28** | 0.34 |

Proof S1

Suppose a variable *y* is related to another variable *x* by the classic scaling equation:

 Eq. S1

The equation is linearized by taking the log10 of both sides:

 Eq. S2

Where *b* is the slope of the line and log10(*a*) is the elevation.

If we have two data sets with different elevations, that is, there is a displacement in *y* between their regression lines, then log10(*a*1) ≠ log10(*a*2). Constructing a scaling relationship for each data set gives:

 Eq. S3

and

 Eq. S4

If the two data sets also have the same slope, *b*1 = *b*2, for any given point on *x*

 Eq. S5

So that

 Eq. S6

and

 Eq. S7

Combining Eq. S6 and Eq. S7 gives

 Eq. S8

which simplifies to

 Eq. S9

 Eq. S10

Substituting *k*1 and *k*2 for the elevations (because log-transformed values are returned from analysis) gives

 Eq. S11

And inverting the logarithm gives

 Eq. S12

Allowing the calculation of the ratio of *y* values for any given *x* directly from the differing elevations of the two lines of common slope. Note: the choice of base 10 logarithms is arbitrary; if the natural log (ln, base *e*) is used for all calculations, the final expression is.