Estimates of fossil hominin quadriceps physiological cross-sectional area from patellar dimensions

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BACKGROUND

The fossil record almost exclusively leaves behind isolated osteological elements. While information on the morphology of the muscles would aid efforts to reconstruct locomotion and other aspects of fossil hominin biology, previous attempts to predict muscle parameters from bones have often failed (see Zumwalt, 2005). It is difficult to quantify the expanse of a muscle attachment site along long bone shafts, nor is there a significant relationship between long bone and muscle cross-sectional areas (Shaw, 2010).

The patella, a sesamoid bone in the quadriceps tendon, may provide an accurate measure of quadriceps morphology because of its intimate relationship with the extensor muscle complex from which it is derived. Here, we present evidence that patellae are a reliable indicator of quadriceps physiological cross-sectional area (PCSA) in extant primates and other mammals. PCSA reflects a muscle’s ability to produce force, and may be an important anatomical variable for locomotor performance. A strong functional relationship between patellar dimensions and quadriceps PCSA could allow for the estimation of muscle morphology and locomotor performance in fossil taxa.

Reliable estimates of fossil hominin muscle parameters are critical for evaluating the transition from relatively small hominoid to relatively larger human lower limb musculature (Figure 4) likely related to an increase in home range size over the course of hominid evolution.

QUESTION

Is the patella a reliable predictor of quadriceps PCSA in extant and fossil taxa?

MATERIALS AND METHODS

Sample

Quadriceps PCSA for extant taxa was taken from the literature (Table 1). The availability of quadriceps PCSA data for primates and other taxa limited the sample of measured taxa for this study. Patellar and femoral linear measurements (Table 2) were taken from mixed-sex samples of wild, shot, and specimens with no evident pathology.

Measurements

Patella

• Superior-Inferior Height (SI)*
• Anterolateral Width (ML)*
• Anterior-Posterior Thickness (AP)*

Femur

• Superior-Inferior Head Diameter (FHSI)*
• Bicondylar Length (FBL)*

Calculated Patellar Planes

• Sagittal Cross Sectional Area (SCSA)
• Transverse Cross Sectional Area (TCSA) = AP*ML

Analyses

Published quadriceps PCSA were regressed against species-averaged patellar and femoral dimensions using Ordinary Least Squares (OLS) (Fig. 3, Table 2) and Phylogenetic Generalized Least Squares (PGLS) (Table 3) regressions. Analysis of variance (ANOVA) was used to identify the metrics most related to quadriceps PCSA (Table 2). The best regressions were used to predict fossil hominin quadriceps PCSA (Table 4).

REFERENCES


ACKNOWLEDGEMENTS

Funding: This study was supported by the NYCEP Integrated Graduate Education and Research Training (IGERT) Fellowship, NSF IGERT grant DGE-1334145 (K.R.R.).

DISCUSSION AND CONCLUSIONS

The patella can reliably be used to estimate quadriceps size (Fig. 3, Table 4).

• Patellar cross sectional dimensions (SCSA, TCSA) are better predictors of quadriceps physiological cross sectional area (r²=0.95, 0.92 respectively) than femoral head size (as a body size proxy) alone (r²=0.80) (Fig. 3, Table 2). Phylogenetic relatedness does not significantly affect this relationship (Table 3).

• This relationship holds broadly among mammals, including hominoids and other primates (Fig. 1, Table 3). However, a larger sample is needed to determine whether the relationship holds in other groups.

Members of the genus Homo have relatively larger patellae and estimated quadriceps PCSA for their body size than A. sediba and P. robustus (Fig. 4, Table 5).

• This has implications for locomotor reconstructions of extinct hominins. Relatively smaller patellae (and lower quadriceps PCSA) may suggest less terrestrial travel and smaller home range size. Muscle size is related to both strength and endurance in primates and other mammals (Weibel et al., 2004).

RESULTS

Table 1. ANOVA of OLS Models

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Variable</th>
<th>Prediction (SCSA)</th>
<th>Prediction (TCSA)</th>
<th>Quadriceps Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK 32</td>
<td>OLS Regression</td>
<td>y = 0.02 + 0.0004</td>
<td>F = 33.170 ***</td>
<td>SCSA 5.926-08 **</td>
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<td></td>
<td></td>
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<td></td>
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Table 2. Quadriceps dimensions are more closely related to patellar size than to other measures of body size.

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Figure 3. Quadriceps dimensions are more closely related to patellar size than to other measures of body size.

Figure 4. Extant Hominoid Relative Hind Limb Muscle Mass

Figure 5. Human-like relative patellar size is present in fossil members of the genus Homo.