SCALING OF HUMAN LOWER EXTREMITY MUSCLE ARCHITECTURE TO SKELETAL DIMENSIONS

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INTRODUCTION

Modeling is widely used by investigators to understand neuromusculoskeletal disorders. Architectural properties of the muscles in these models are based on estimates from a relatively small sample of cadaveric specimens [1,2]. Given that the skeletal dimensions of modeled individuals will almost certainly vary from the skeletal dimensions of the cadaveric specimens, architecture must be scaled to match the skeletal dimensions of the modeled subjects. However, these assumptions have never been tested in humans. Therefore, the purpose of this study was to define the scaling functions of human architecture to measured skeletal dimensions.

METHODS

Eight formaldehyde-fixed cadavers were prepared by skinning and isolating the quadriceps and hamstring muscles. The mass of each muscle was measured after dissection and isolation from adjacent muscles. Fiber lengths and pennation angles were measured from three to five predetermined locations within each muscle using digital calipers and a goniometer. Sarcomere lengths for each muscle fiber bundle were determined by laser diffraction using the zeroth to first order diffraction angles as previously described [3]. To account for variations in muscle fiber length that occur during fixation, fiber bundle lengths were normalized by scaling measured sarcomere length to a standard sarcomere length for human muscle of 2.7 μm [4]. Using these normalized muscle fiber lengths, PCSA was calculated using the following equation [5]:

$$\text{PCSA } (\text{cm}^2) = \frac{\text{Mass (g)} \bullet \cos\theta}{\rho\ (\text{g/cm}^3) \bullet L_f\ (\text{cm})}$$

where ρ represents muscle density (1.112 g/cm^3) [6] and θ represents surface pennation angle.

Femur length (cm; distance from the greater trochanter to the lateral epicondyle) and body mass (kg) were measured as potential scaling factors for fiber length and PCSA, respectively. Since body mass was only available for five cadaveric specimens, statistics scaling PCSA based on mass was restricted to these samples. Simple linear regression was used to determine the slope and strength of the association between architectural measurements and skeletal dimensions.

RESULTS AND DISCUSSION

Muscle fiber length scaled poorly with femur length. In fact, only fiber length of the short head of biceps femoris scaled with femur length. In contrast, PCSA scaled well with body mass (Table 1). Although rectus femoris, vastus medialis and semitendinosus did not have statistically significant model fits, the PCSA of these two quadriceps muscles had good model fits and were close to achieving significance (*p-values* 0.05-0.06).

CONCLUSIONS

Although more data are needed to fully elucidate these scaling relationships, these data represent a more robust sample than previous studies estimating architectural values [1,2]. However, based on these data, it appears that PCSA scales well with body mass but muscle fiber length does not scale, in general to femur length.

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Table 1: Scaling relationships for muscle fiber length versus femur length and PCSA versus body mass.

	Fiber Length		Physiological Cross-Sectional Area	
Muscle	**Slope**	**r^2**	**Slope**	**r^2**
Rectus femoris	-0.033	0.012	0.307	0.749
Vastus lateralis	0.124	0.142	1.125*	0.994
Vastus intermedius	0.201	0.173	0.338*	0.793
Vastus medialis	0.046	0.025	0.566	0.764
Biceps femoris LH	0.352	0.260	0.424*	0.881
Biceps femoris SH	0.395*	0.571	-	-
Semitendinosus	-0.0441	0.005	0.035	0.027
Semimembranosus	0.0286	0.004	0.548*	0.925

*indicates significant regression model fit.