INTRODUCTION

The human quadriceps and hamstring muscle groups are arguably the most thoroughly studied human muscle groups by virtue of their functional and clinical importance. This provides the motivation for us to integrate muscle, joint and tendon properties of the knee as has been accomplished for the wrist (Loren et al. 1996). This will enable us not only to understand the design and function of the knee, but also to recommend rationale interventional procedures that might be used to alter function or alleviate pain.

METHODS

Ten formaldehyde-fixed cadaveric lower extremities were used for this project (age: 82±10 yrs.; gender: 3 female-7 male; height 169.5±9.7 cm; weight 82.7±15.3 kg).

Muscle architectural measurements were made on the four quadriceps and four hamstrings muscles according to methods previously described (Lieber et al. 1990). The specific muscles studied were (n=10/muscle): Vastus lateralis (VL), vastus medialis (VM), vastus intermedius (VI), rectus femoris (RF), short head of biceps femoris (BFSH), long head of biceps femoris (BFLH), semitendinosus (ST), and semimembranosus (SM). Briefly, mass and muscle length were measured for each muscle. Fiber bundles from three to five predetermined regions of each muscle were microdissected and sarcomere length was measured in each fiber bundle using laser diffraction (Lieber et al. 1984) to calculate normalized fiber length and physiological cross-sectional area (PCSA) as previously illustrated (Lieber et al. 1990).

Statistical analysis consisted of analysis of variance (ANOVA) and post-hoc least-squared differences (LSD) tests were performed to make paired comparisons among muscles. All results are shown as mean ± standard error, and the significance level was α=0.05.

RESULTS AND DISCUSSION

In contrast to previous reports (Wickiewicz et al. 1983 and Friederich and Brand, 1990) muscle fiber lengths were not significantly different between quadriceps and hamstrings groups. However, within the quadriceps, RF fiber lengths (80.69±3.44 mm) were significantly shorter than VL (92.70±6.40 mm), VI (95.92±5.30 mm), and VM (93.12±5.41 mm) (Fig. 1, P<0.05).

Similarly, within the hamstrings, SM fiber lengths (58.56±7.51 mm) were significantly shorter than the ST (124.07±12.61 mm), BFSH (105.02±8.17 mm), and BFLH (105.19±4.23 mm) (Fig. 1, P<0.05).

PCSA was significantly larger in quadriceps
compared to hamstrings ($P<0.05$). Within quadriceps, VL PCSA (36.18±4.54 cm$^2$) was significantly greater than RF (14.26±1.58 cm$^2$), VI (22.83±3.72 cm$^2$), and VM (21.46±2.70 cm$^2$) (Fig. 1, $P<0.05$). Within hamstrings, the SM had a significantly larger PCSA (22.64±2.99 cm$^2$) than BFSH (6.07±0.48 cm$^2$, Fig. 1, $P<0.05$) but was not significantly larger than any of the quadriceps muscles. Interestingly, fiber length variability was small (7%-11%) for all muscles except the ST which had the greatest coefficient of variation of all muscles (35±4%; $P<0.05$).

**Figure 1:** Scatter plot of normalized muscle fiber length vs. PCSA. (Hamstrings, ○; Quadriceps, ●); Values are plotted as mean ±SEM. Abbreviations as in Methods.

These data clearly show, that considering only architectural properties, quadriceps and hamstring muscles differs primarily in their PCSA. This is not surprising, as the quadriceps (which had the largest PCSAs) are antigravity muscles at the knee. Muscle fiber lengths did not differ between muscle groups, contrary to previous reports (Wickiewicz et al. 1983 and Friederich and Brand, 1990). This is somewhat surprising, not only based on the “legacy” established by the two previous landmark studies, but because hamstring muscles are largely comprised of two-joint muscles. It is also interesting that the only two-joint muscle in the quadriceps (rectus femoris) had the shortest fiber length of quadriceps (Fig. 1).

Within muscle groups, hamstrings demonstrated the classic trade-off between PCSA and fiber length. Specifically, the SM had a large PCSA but short fibers while, at the other extreme, BFSH had a small PCSA but longer fibers (Fig. 1). The quadriceps did not follow this classic pattern. The VL had both the largest PCSA and the longest fibers. Functionally this would mean that the VL has both the greatest force generating capacity and the greatest excursion of the quadriceps.

**SUMMARY/CONCLUSIONS**

Clinically these results are important for a number of reasons. First, the data support the notion that the VL muscle is the “key” to knee function. Second, previous reports that hamstring muscles are designed for excursion is not supported by these data. In fact, as a whole, they are no different from quadriceps muscles, despite their two joint function. The specific implications of these results remain to be determined.

**REFERENCES**


**ACKNOWLEDGEMENTS**

This work was supported by the Department of Veterans Affairs and NIH grants HD048501 and HD050837.