Beyond the sagittal plane: contracting fascicles rotate in the coronal plane while enhancing longitudinal force transmission in human vastus lateralis

Katsuki Takahashi[1], Jun Umehara[2,3], Masahide Yagi[3], Raki Kawama[1], David J. Saxby[4], Taku Wakahara[1]
[1]Doshisha University, Kyoto, Japan, [2]Kansai Medical University, Osaka, Japan,
[3]Kyoto University, Kyoto, Japan, [4]Griffith University, Gold Coast, Queensland, Australia
Email: kattakah@mail.doshisha.ac.jp

Summary

Fascicle contraction dynamics influences skeletal muscle mechanical performance, but their nature outside the sagittal plane remains unclear. By using diffusion tensor imaging (DTI), we show that human vastus lateralis (VL) fascicles rotate in the coronal but not sagittal plane during submaximal contraction. The fascicle coronal rotation decreases the muscle's short-axis force transmission while enhancing the longitudinal force transmission efficiency. Findings highlight the three-dimensional (3D) nature of contracting fascicle dynamics beyond the current sagittal plane paradigm.

Introduction

Skeletal muscles change their internal architectures (fascicle length and orientation) upon contraction, largely influencing the mechanical output [1]. In pennate muscle where angulated fascicles transmit a portion of their tensile force along the aponeurosis (the sheet-like tendon within the muscle), it is well documented that fascicles rotate around their attachment and modify the force transmission onto the aponeurosis during contraction [1]. However, the current understanding of contracting fascicle dynamics is limited to the sagittal (perpendicular to the aponeurosis) plane; their 3D nature remains uncertain. Here, we tested our hypothesis that muscle fascicles rotate in 3D and modify their tri-axial force transmission within contracting human VL *in vivo*, by using DTI [2].

Methods

Nine healthy adults (27±4 yrs, 170±5 cm, 69±10 kg) lay supine on a 3 T magnetic resonance imaging scanner with their right hip and knee flexed to 30° and 20°, respectively. Axial images of the right thigh were scanned during rest and during sustained voluntary isometric knee extension contractions (corresponding to 20% of root-mean-squared electromyographic amplitude of VL during maximal voluntary isometric knee extension), using Dixon (covering the whole thigh, scan time: 60 s in total) and DTI (10 cm around 50% of the thigh length, scan time: 119 s) sequences.

Using the Dixon and denoised DTI, the muscle belly, deep aponeurosis, and fascicles of the right VL were reconstructed in 3D space (Figure 1A). For the medial, center, and lateral regions, we calculated fascicle (force vector) angle in sagittal and coronal (parallel to aponeurosis) planes. We also calculated fascicle force fraction along three orthogonal axes (F_{length}, $F_{\text{thickness}}$, and F_{width}) of the aponeurosis around the fascicle insertion for each region.

Results and Discussion

At the rest, fascicles in all regions showed angulation both in sagittal and coronal planes. From resting to contracting states, fascicle sagittal angle did not change in any regions (Figure 1b). Meanwhile, fascicle coronal angle decreased upon contraction in the medial region ($p = 0.03$) but not in the other regions, which may be affected by the iliotibial band above the lateral/center region of VL. Interestingly, F_{width} of medial fascicles was reduced by contraction ($p = 0.01$). This F_{width} decrease was strongly correlated with F_{length} increase ($r = 0.85$, $p < 0.01$), indicating that the short-axis force decrease by fascicle coronal rotation results in enhancing longitudinal force transmission.

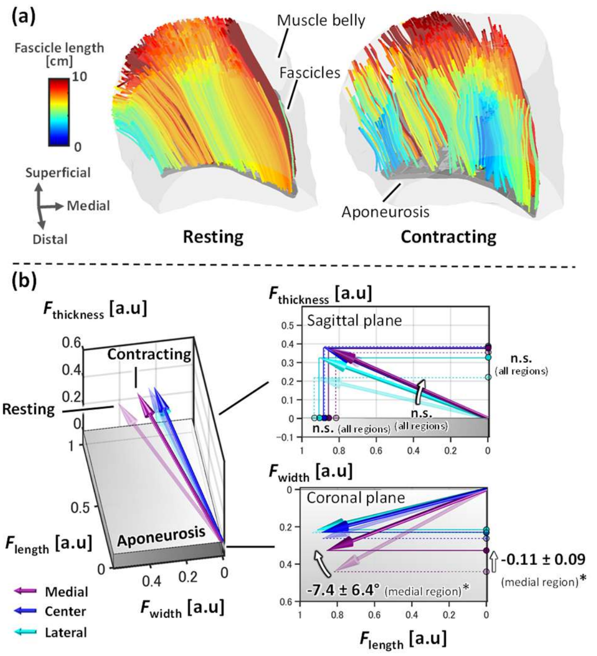

Figure 1: (a) Examples of muscle fascicle 3D reconstruction. **(b)** Fascicle force vectors in all regions (group mean). *: $p < 0.05$

Conclusions

During submaximal contraction, pennate muscle fascicles can rotate outside the sagittal plane in a region-specific manner. Coronal fascicle rotation during contraction likely leads to increases in the longitudinal force transmission and the mechanical efficiency of contracting muscles.

References

[1] Roberts TJ et al. (2019). Physiology, **34**: 402-408.
[2] Takahashi K et al. (2025). J Biomech, **179**: 112488.