Automated Fascicle Tracking to Characterize Changes in Muscle Architecture During Isokinetic Contractions

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Introduction

Characterizing muscle architecture during functional movements provides important insight into the muscle mechanics underpinning musculoskeletal pathologies. Ultrasound imaging is a valuable tool to non-invasively observe changes in muscular structure for pennate muscles throughout a contraction. However, quantifying architectural parameters such as muscle fascicle length and pennation angle from ultrasound frames remains a challenge. Manually measuring these parameters are time and labor intensive. Conversely, automated tracking using computer vision offers efficient techniques improved research workflow and reliability. To address this research need, we have developed an automatic fascicle tracking algorithm that can be used by researchers to track fascicles and automatically extract pennation angle and fascicle length throughout a contraction. The purpose of this study was to quantify the reliability of this algorithm for quantifying medial gastrocnemius architecture during maximal effort plantarflexion contractions performed on a dynamometer.

Methods

Five healthy-young adults performed maximal effort plantarflexion contractions and provided written informed consent in this IRB approved study. Images of the medial gastrocnemius of the right leg were acquired using an ultrasound transducer at 60 Hz at 8 MHz (LV7.5/60/128Z-2, SmartUs, TELEMED), which was secured in place using a custom-made molded cast secured by straps. Subjects were supine on a treatment table, which was secured to an isokinetic dynamometer (System 4, Biodex), with their right foot secured to the dynamometer footplate. Subjects performed maximal-effort isometric contractions at neutral ankle position and isokinetic contractions at 30, 120, 210, 300, and 500 degrees per second. We provided subjects with real-time feedback of plantarflexion torque using a computer monitor to encourage maximal effort. Subjects performed 3-4 contractions per condition until torque output plateaued over three trials. During each contraction, we synchronized ultrasound images with dynamometer angular position, velocity, and torque. We analyzed these videos using a three observation-three observer design to determine intra-rater and inter-rater reliability, respectively. To analyze each trial, users identified the deep and superficial aponeuroses and a muscle fascicle in the first frame of the video. Each of these structures were seeded with 100 tracking points, which were used to fit a line and define the aponeuroses and fascicle (Figure 1:A). Next, we tracked each one of these points frame by frame using affine optical flow in the MATLAB computer vision toolbox (Nanick MA, Mathworks) and automatically redrew the lines in each frame based on the movement of the seeded points to calculate fascicle length and pennation angle. Following the completion of automatic tracking for a given contraction, users identified the fascicle by drawing a line from the fascicle insertion in the deep aponeurosis in six evenly spaced frames across each contraction to serve as a comparison to the automatic tracking measurement (Figure 1). We used linear regression to evaluate the correlation between the manual and automatic measurements of fascicle length and pennation angle across all contractions for all subjects. We also calculated the reliability of both the manual and automatic

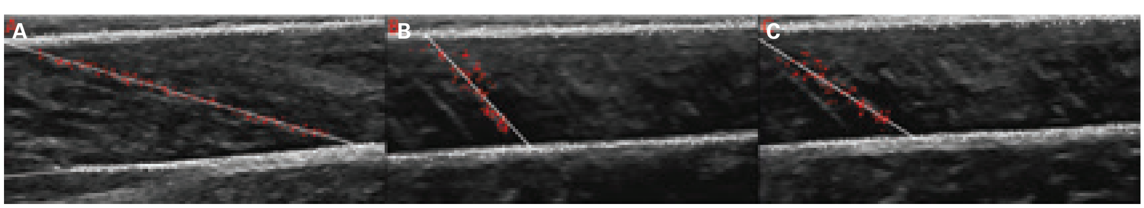

Figure 1. Dynamic ultrasound images of the medial gastrocnemius muscle while a patient performs a maximal plantarflexion contraction demonstrates the shortening dynamics of the muscle. To increase analysis speed and repeatability, users identify the deep and superficial aponeurosis as well as a single-continuous fascicle with the foot in dorsiflexion **(A).** Next, an affine optical flow paradigm tracks these structures through neutral position **(B)** and into peak plantarflexion **(C).** Our automated tracking algorithm has the strongest agreement with manual tracking when the muscle is actively shortening **(AB)** but tends to under-approximate fascicle pennation and over-approximate fascicle length when the muscle is fully shortened **(C).**

tracking paradigms between days and examiners was using intraclass correlation coefficient (ICC). This test produced values ranging between 0 and 1 where values above 0.7 indicated "good" reliability between measurement methods.

Results

Over 5,000 individual muscle fascicles were manually identified by the three examiners. The mean difference between manual and automatic fascicle length measurement was -4.49 ± 7.1 mm. The mean difference between manual and automatic pennation angle was 5.56 ± 7.6 degrees. These differences represent errors of 5.13% and 10.2 % of the dynamic range of fascicle lengths and pennation angle respectively. Manual and automatic fascicle length and pennation angle measurements were highly correlated across all contractions, subjects, examiners, and days (0.89 and 0.85, respectively). Both the manual and automatic fascicle length measurements had 'good' reliability between days for each examiner (0.75 and 0.92, respectively). Manual and automatic measurements of fascicle length also had 'good' reliability between all examiners (0.88 and 0.79, respectively).

Discussion

We observed good measurement reliability across examiners between days and between examiners across all days for both manual and automatic tracking. Our findings indicate that this tool can be used by different users to reliably quantify fascicle architecture from ultrasound images acquired during maximal effort contractions. While the automatic measurements of fascicle geometry were on average longer and less pennate than manual measurements, especially at end-stages of contraction, there were many well-tracked fascicles as shown in (Figure 1:AB). We have observed that this under approximation (Figure 1:C) occurs when seeded points are initially selected over non-fascicle tissue such as veins which upon contraction do not move in concert with the rest of the muscle. These structures are often not evident in the first fame of the video and could be avoided by selecting a different fascicle if given another chance to initialize the program. This study used only the first attempt at tracking regardless of observed tracking quality. As such, these results represent a "worst-case-scenario" for tracking performance which we believe will drastically improve if users can reinitialize the program after observing a poorly tracked fascicle. Current work is focused on optimizing this automatic tracking paradigm to improve measurement fidelity.

Clinical Relevance

Muscle function is dictated by the ability of muscles to change shape during contractions. However, the technical challenges of analyzing large data sets of ultrasound images limits the feasibility of implementing these measurements in a large scale. This work provides a reliable automated framework for extracting these architectural data from images of patient muscle.

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