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Determining 3D Muscle Architecture using Ultrasound Imaging

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***Abstract*— In vivo determination of skeletal muscle architecture is often implemented with Diffusion Tensor Imaging (DTI). In comparison to ultrasound imaging, DTI requires longer acquisition times, is costlier, and is much less portable than ultrasound. This work aims to determine pennation angles from 3D freehand ultrasound images. To this end, we reconstructed 3D volumes by simultaneously obtaining ultrasound images and optical marker data. We computed fascicle orientations using a multiscale vessel enhancement filtering method.**

I. INTRODUCTION

Architectural parameters of skeletal muscle such as pennation angle provide valuable information on the muscle's functionality. Determination of these parameters in vivo and in 3D often relies on Diffusion Tensor Imaging (DTI). Compared to DTI, ultrasound imaging provides benefits such as being less expensive, more portable and enabling faster and more flexible examinations. To date, 3D freehand ultrasound applied to skeletal muscle has generally focused on acquiring muscle volume.

In this work, we present a method to use 3D freehand ultrasound for determining muscle volume and fascicle orientations in 3D.

II. METHODS

We acquired ultrasound images of the tibialis anterior (TA) muscle from a healthy 30-year-old male using a Supersonic Imagine Aixplorer MACH30 at a frequency of 35Hz. We placed reflective markers on a 3D printed transducer holder. Marker positions were captured with an 8-camera VICON motion capture system at a frequency of 200Hz. We triggered both systems simultaneously using an Arduino. For the Image-to-Probe calibration, we used a Single Wall Calibration algorithm [1].

Custom Matlab (R2020a) code was written to perform the 3D reconstruction including bin-filling based on a nearest-neighbor algorithm and hole-filling for interpolation. We segmented the superficial and the deep compartment of the TA and its aponeurosis using The Medical Imaging Interaction Toolkit (MITK, v2021-02).

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To determine fascicle orientations, we used a method for Multiscale Vessel Enhancement Filtering [2,3]. We derived the initial fascicle orientations from the enhancing filter. Subsequently, we interpolated the orientations between the fascicles. Paraview (Version 5.8.0) was used for the visualization of the fiber tractography.

We defined the pennation angle as the angle between the fascicle direction vector at each voxel and the longitudinal axis of the aponeurosis.

III. RESULTS

From visual inspection, the obtained fascicle orientations are aligned with the sagittal view of the 3D-reconstructed ultrasound images, where the connective tissue between fascicles is visible in light gray (Figure 1).

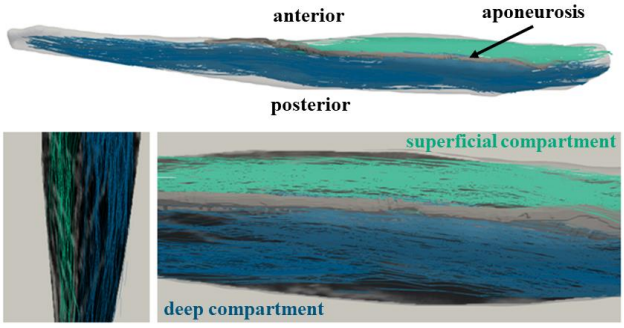

Figure 1: Fascicle tracts in the whole TA (top), sections with underlying sagittal B-mode images (bottom), including aponeurosis in dark gray, the superficial compartment in green, the deep compartment in blue.

Figure 1 shows that the fascicle directions are different for the superficial and the deep compartment, as expected.

IV. DISCUSSION & CONCLUSION

This work proposes a novel method to determine fascicle orientations from 3D freehand ultrasound measurements, as a flexible and portable approach overcoming typical drawbacks of DTI. In future studies, we will verify this method using data from additional subjects and comparison to DTI data.

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