AN ALGORITHM FOR AUTOMATED TRACKING OF TENDON EXCURSION FROM ULTRAOUND IMAGES

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INTRODUCTION

One commonly-used method for measuring muscle moment arm is the tendon excursion method, in which moment arm is calculated as the first derivative of the displacement of the tendons with respect to the joint angular displacement (An et al., 1983). This method has been used to estimate moment arms in cadaver specimens through direct attachment of transducers to tendons (e.g., Brand et al., 1975). It has also been applied *in vivo* through ultrasound imaging of tendon displacement (e.g., Maganaris et al., 2000), but this technique usually requires manual digitization of landmarks on each frame of the image sequence. An automated method for tracking the tendon would provide a time-efficient means for evaluating muscle moment arms in clinical and research settings. The purposes of this study were to develop a novel automated tendon tracking algorithm that incorporates the Lucas-Kanade algorithm for calculating optical flow (Lucas & Kanade, 1981) and to test the accuracy of the algorithm using phantom, cadaver, and *in vivo* experiments.

METHODS

Automated tracking was implemented using an algorithm which computes pixel velocities based on spatial and temporal image brightness which is assumed to be constant from frame-to-frame. A pyramidal approach with increasing resolution from top to bottom allows for large pixel velocities to be calculated. By adding the average of the five greatest pixel velocities within a region around the selected landmark to the initial selected pixel, the pixel location in the subsequent frame can be estimated. Three experiments were conducted for validation: (1) a wire "phantom" was moved through three nominal distances (approx. 5 mm, 10 mm, and 20 mm) while ultrasound images of the wire were captured. The wire excursion estimated using automated tracking was compared to direct measurements made with a cable extensometer attached to the wire; (2) *in vitro* excursion of the lateral gastrocnemius tendon estimated using manual tracking were compared to direct measurements of tendon excursion made using a cable extensometer in a fresh-frozen lower-leg cadaver specimen; (3) i*n vivo* excursions of lateral gastrocnemius tendon estimated using automated tracking were compared to excursions estimated using manual landmark identification in five subjects (Figure 1).

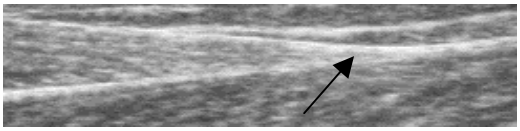

Figure 1. Ultrasound image of lateral gastrocnemius. The arrow indicates the musculotendon junction as the tracking landmark.

This three-tiered approach for validation was implemented because the automated tracking algorithm did not perform consistently on cadaver ultrasound images, perhaps because of tissue degradation due to dehydration, freezing, and thawing.

Ultrasound images were acquired at 30 Hz using an Aloka 1000 scanner operating in B-mode with a 7.5 MHz probe. Root-mean-squared errors (RMSE) were computed for comparisons of wire or tendon excursion measured by either the cable extensometer, manual tracking, or automated tracking as described above.

RESULTS AND DISCUSSION

RMSE between direct measurement and automated tracking of the wire for the phantom experiment averaged across ten trials were 0.2 ± 0.1 mm, 0.4 ± 0.1 mm, and 0.9 ± 0.2 mm for mean excursions of 5.1 mm, 8.9 mm, and 19.3 mm, respectively (Figure 2a). RMSE between manual tracking of ultrasound and direct measurement in the cadaver model, averaged across five trials, were found to be 2.30 ± 0.7 mm for sagittal plane movements and 0.30 ± 0.1 mm for frontal plane movements (Figure 2b). RMSE between manual tracking and automated tracking measured in vivo averaged across five trials were found to be 1.1 ± 0.3 mm for sagittal and frontal plane movements, respectively (Figure 2c).

Good agreement was found between direct and automatically tracked measurements of wire excursion, between manually-tracked and direct measurements of tendon excursion in cadaver specimens, and between manually-tracked and automatically tracked tendon excursion *in vivo*. Relative to the total tendon excursion which was about 17-30 mm for sagittal plane motions and 2-7 mm for frontal plane motions, the RMSE found in this study suggest that errors in moment arms computed from automated tracking of tendon excursion would amount to less than 10%.

SUMMARY/CONCLUSIONS

These small errors and ease of use of the automated tracking method suggest that the method could be a useful, effective, and time-efficient clinical tool for assessment of moment arms of superficial muscles.

REFERENCES

Brand, P.W. et al. (1975). *J Bone Joint Surg Am*, **57**, 779-784.

Lucas, B.C. and Kanade, T.. (1981). *Proc. DARPA*, 121-130

Maganaris, C.N. (2000). *J Biomech*, **33,** 375-379.

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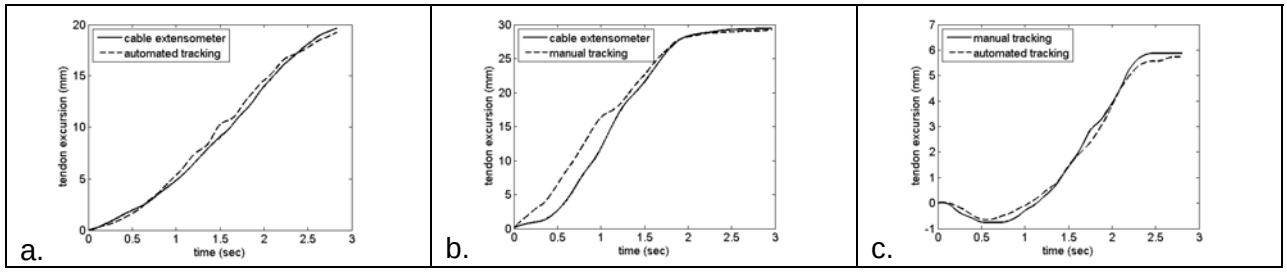

Figure 2. Typical examples of a) phantom measurements by direct measurements versus automated tracking (RMSE = 0.77 mm), b) *in vitro* measurements by direct measurements versus manual tracking (RMSE = 2.21 mm), c) *in vivo* measurements by manual tracking versus automated tracking (RMSE = 0.21 mm).