RELIABILITY OF AN AUTOMATIC TRACKING ALGORITHM TO MEASURE PASSIVE AND ACTIVE MUSCLE FASCICLE LENGTH CHANGES FROM ULTRASOUND

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SUMMARY
B-mode ultrasound can be used to non-invasively image muscle fascicles (bundles of fibres) in vivo. The process of tracking muscle fascicle length changes during passive movements and voluntary contractions over time is typically performed manually, and is highly subjective and time consuming. This study assessed the reliability of a new computer algorithm for automatically tracking muscle fascicle length changes from ultrasound images. The algorithm used was the Lucas-Kanade optical flow algorithm with an affine optic flow extension. Six subjects performed passive movements, and concentric and eccentric contractions of the ankle plantarflexors on a Biodex isokinetic dynamometer. Sagittal plane ultrasound images were simultaneously collected from the medial gastrocnemius (MG) muscle. Within- and between-examiner reliability was quantified using the coefficient of multiple determination (CMD). CMD’s across all test conditions ranged from 0.50 to 0.93 and were all above 0.98 when the systematic error was removed. The within- and between-examiner CMD’s were 0.86 and 0.70 respectively. When the systematic error was removed, these CMD’s improved to 0.99 and 0.98. Overall findings indicate that the automatic tracking algorithm is a reliable method for the measurement of MG muscle fascicle length changes in vivo.

INTRODUCTION
Muscle fibre length is an important determinant of the force-generating capability of muscle, with shorter muscle fibres having a narrower force-length relation, a reduced maximum shortening speed and a reduced length at which they develop passive forces [1]. The length change of the muscle fibres may not be reflected by joint motion alone. Therefore to examine the dynamic function of muscles during contractions and movement, it is necessary to examine the length changes of the muscle fibres themselves.

It is currently difficult to image individual muscle fibres in vivo, however B-mode ultrasound can be used to non-invasively visualise muscle fascicles (bundles of fibres) in vivo. One of the difficulties associated with ultrasound concerns the means by which fascicles length changes are tracked over time. Manually digitizing ultrasound images is the most common method [2,3], but this technique is time consuming and highly subjective. Several automated techniques have been developed to track muscle and tendon movement in vivo, including cross-correlation [4], block matching [5] and optic flow algorithms [6]. The accuracy of these techniques is limited by the regions of interest that are visible throughout the entire imaging sequence and their reliability is dependent on the regions that are selected and whether distinguishable features are consistently present from one frame to the next.

We applied an extension to the Lucas-Kanade optical flow algorithm [7] incorporating an affine optic flow model [8]. This algorithm seeks to determine the global movement of visible muscle from one frame to the next during muscle contractions. Essentially, the transformations in the image due to shear and rotation as well as translation are calculated based on the optic flow. This type of tracking is physiologically relevant because muscle fascicles both shorten and rotate during muscle contraction, which can be modelled by the affine transformation.

The purpose of this study was to determine the within and between assessor reliability of in vivo MG passive and active (i.e. isometric, concentric and eccentric) fascicle length changes from two-dimensional B-mode ultrasound using the affine flow algorithm.

METHODS
Six male subjects (age: 30 ± 4 years, body mass: 79 ± 6 kg, height 180 ± 5 cm) performed bilateral passive movements, isometric and concentric and eccentric contractions of the ankle plantarflexors on a Biodex isokinetic dynamometer. Sagittal plane B-mode ultrasound images were simultaneously collected from the MG muscle.

From the saved ultrasound images, the examiner selected the muscle region of interest and defined the average initial length of the muscle fascicles by defining fascicle end-points in the first frame for analysis. The muscle region of interest was defined as the area between the superficial and deep fascia of the MG muscle that was visible in the ultrasound image. Muscle fascicle length was defined as the straight line distance between the superficial and the deep muscular fascia parallel to the lines of collagenous tissue visible on the ultrasound image. Fascicle length changes were subsequently tracked using a Lucas-Kanade optical flow algorithm with affine optic...
flow extension. The algorithm implements a least squares fit of the parameters to estimates of the spatial and temporal grey-level gradients on a rectilinear grid within the defined region of interest. The calculated affine transformation is then applied to the defined fascicle end points from one frame to the next (which may be applied outside of the region of interest). This iterative approach allows for fascicle length changes to be defined for each frame of ultrasound video.

The algorithm was implemented in a custom Matlab graphical user interface. To assess within-examiner reliability, one assessor tracked fascicle lengths at each condition on three occasions. Between-examiner reliability was assessed from fascicle lengths tracked by three separate examiners for each condition. Within- and between-examiner reliability was computed using the Coefficient of Multiple Determination (CMD).

RESULTS AND DISCUSSION
CMD’s across all test conditions ranged from 0.50 to 0.93 and were all above 0.98 when the systematic error (SE) due to the estimate of the initial fascicle length on the first ultrasound frame was removed (Figure 1). The overall within- and between-examiner CMD’s were 0.86 and 0.70 respectively. When the SE was removed, these CMD’s improved to 0.99 and 0.98.

The SE ranged from 2.7 mm to 7.4 mm across all test conditions. The SE was greatest in PS movement between-examiners and in ECC condition for the within-examiner analysis. The overall within- and between-examiner SE’s averaged across all test conditions were 4.16 ± 3.56 mm and 5.09 ± 3.81 mm respectively.

Given that the corrected CMD represents the repeatability of the tracking process, these findings indicate that the automated tracking algorithm was highly repeatable and that the unexplained variability in the uncorrected CMD’s was primarily due to the within and between assessor differences in the estimate of the initial fascicle length in the first ultrasound frame for analysis. Comparisons with manual tracking in a subsample of our data also suggest auto-tracking can be performed about 10 times faster than manual tracking of the same trials.

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CONCLUSIONS
• Passive and active muscle fascicle length changes can be reliably tracked using an automated method by either the same or different assessors.
• The Lucas-Kanade affine flow algorithm is highly repeatable and the unexplained variability in the uncorrected CMD’s was primarily due to the within and between assessor differences in the estimate of the initial fascicle length in the first ultrasound frame for analysis.
• The objectivity and efficiency associated with automated fascicle tracking make this a promising approach for studying muscle fascicle behaviour in a wide variety of applications in the clinical and movement sciences.

REFERENCES