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The Reliability of Musculoskeletal Ultrasound Video Tracking of Muscle and Tendon Displacement

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***Abstract*- Introduction:** Lateral epicondylalgia [LE] is most common cause of elbow pain attributed to abnormalities in the extensor carpi radialis and extensor digitorum communis [EDC]. Quantifying the linear displacement using musculoskeletal ultrasound and the Motion Tracking Analysis Program [MTAP] may be useful in characterizing the abnormalities found in elbows with LE. This study investigated the reliability of the operators [i.e. sonologist and sonographer] and the reader [i.e. physiotherapist] in procuring and analyzing ultrasound videos using MTAP.

Methods: Participants were recruited from private physiotherapy clinics in Adelaide between October 2010 and November 2010. To be included in the study, participants had to be referred to the clinic for symptoms of pain on, or within 3 cm of, the lateral epicondyle and have literacy in the English language. Both elbows of participants were scanned independently by two operators. The videos were analyzed by reader using MTAP.

Results: Fifty two and 60 videos from 12 elbows of six participants were procured by the sonographer and sinologist, respectively. Intra-tester reliability was found to be most acceptable in location 2 [EDC; sonographer: intraclass correlation [ICC]=0.88, 95 percent confidence interval [95% CI] =0.46-0.98 and sonologist: ICC=0.92, 95% CI=0.42-1.00]. Considering all 53 videos, there was an almost perfect agreement in the tracking analysis of the reader [ICC=0.93, 95% CI=0.89-0.96] with most of agreements occurring in location 2 [EDC].

Conclusion: The acceptable reliability of the sonographer, sinologist, and reader in scanning and analyzing ultrasound videos of the EDC suggests they may be used in characterizing EDC movement in elbows with LE and thus, understanding the role of the EDC in the production of pain in elbows with LE.

***Index Terms*-** TENNIS ELBOW, LATERAL EPICONDYLALGIA, TRACKING, ULTRASOUND, RELIABILITY

I. Introduction

Lateral epicondylalgia [LE] is the most common clinical condition causing lateral elbow pain (1). It is secondary to repetitive and forceful activities of the upper extremities (2) and is common in cooks and automobile assembly line workers (3,4). It typically occurs in individuals aged 35 to 60 years (5-7). Elbow pain in LE is associated with the mechanical stresses on the tendinous origins of forearm extensors, specifically of the extensor carpi radialis brevis [ECRB], extensor carpi radialis longus [ECRL], and extensor digitorum communis [EDC] (8-10). The ECRB is most commonly cited as the cause of LE.[9]

Only one study used musculoskeletal ultrasound [MSUS] to investigate the movement of the forearm extensor muscles in elbows with LE. Liu et al. observed the decreased movement of the extensor carpi radialis of two participants with LE after application of elastic tape using a motion tracking program (11). This study did not specifically report testing of the ECRL. However, the figure in the paper points to this part of the extensor carpi radialis. The study did not determine the reliability of the process used in measuring the movement of the ECRL.

Although the ECRB is commonly reported as a cause for LE (8,9,12-14), no one has investigated its linear displacement using a motion tracking program. This may be due to the challenge of sonographically delineating the borders of the ECRB. The ECRB near the lateral epicondyle has a small cross-sectional area and is found deep under the EDC (15). This makes it difficult to measure.

The reliability of tracking movement in the ECRB and EDC using MSUS depends on the MSUS machine and the motion tracking program used. The MSUS videos have to be clear so the muscle or tendon can be followed. The clarity of MSUS videos depends on the skill of the operator and the imaging protocol used. The anatomical site, equipment settings, scanning, and interpretation procedures used all influence the quality of the images obtained (16). The sensitivity also varies between MSUS machines. It is influenced by gain, probe frequency, filtering and pulse repetition rate (16).

Challenges in the use of a motion tracking program are two-fold, namely: 1. difficulty in determining a landmark and 2. non-trackable feature of interest in the moving muscle or tendon (11). The landmark is a relatively fixed structure within the body such as bone. The feature of interest is the part of the muscle or tendon being tracked during body movement (17,18). Without an observable landmark, it may be difficult to locate the feature of interest (11). Once the feature of interest is identified, tracking its movement within the MSUS video is complicated by poor contrast, low signal-to-noise ratio, and typical blur common in MSUS videos (17-18).

Given the many factors influencing the measurement of moving muscle and tendons, the reliability of using a motion tracking program in quantifying the linear displacement of the ECRL and EDC in MSUS videos has to be evaluated. This aims of study are to determine the:

1. standard error of measurement [SE_M] of the reader in using the Motion Tracking Analysis Program [MTAP] in quantifying the linear displacement of the ECRL [muscle] and EDC [muscle and tendons]
2. intra-tester and inter-tester reliability of the sonographer[1] and sonologist[2] in scanning the ECRL and EDC in the elbows of participants with LE.

II. METHODS AND MATERIALS

Oversight

This study was approved by the Human Research Ethics Committee of the University of * *** [ethics application protocol number 21929]. Informed consent was obtained from the participants.

Study Population

The study was conducted at the University of * *** School of Health Sciences [Physiotherapy] Clinic. Participants were recruited from private physiotherapy clinics in Adelaide between October 2010 and November 2010. To be included in the study, participants had to be referred to the clinic for symptoms of pain on, or within 3 cm of, the lateral epicondyle in at least one elbow and have literacy in the English language.

Patients were ineligible for inclusion if they had current general body malaise [which may be indicative of systemic illness], current diagnosis of cancer, previous or current fractures in the upper limb, osteoarthritis of the elbow, recent blunt trauma to the elbow, or previous surgery to the elbow.

Testers

The sonographer had postgraduate qualifications and 20 years of experience in musculoskeletal ultrasound. The sonologist had 20 years of practice in rehabilitation medicine, and had been using MSUS for the past three years. The reader had 10 years of physiotherapy practice and had contributed to the design of the MTAP software particularly used in this study.

Equipment

Musculoskeletal Ultrasound Instrument: Ultrasound measurements were made with a Siemens Antares Sonoline Ultrasound machine [Siemens Medical Solutions, USA, Inc, Ultrasound Group Issaquah, WA] with a 5-13 MHz linear array broadband transducer.

*Mechanical Test Jig***:** Figure 1 shows the mechanical test jig used to control the movement of the elbow and wrist during the MSUS scan. The jig consisted of a wooden plank that positioned the forearm in pronation and supported the elbow in extension. A universal goniometer was used to measure wrist flexion.

[1] Sonographers are diagnostic medical professionals who perform ultrasonic imaging, [2] Sonologists are medical doctors who perform ultrasonic imaging.

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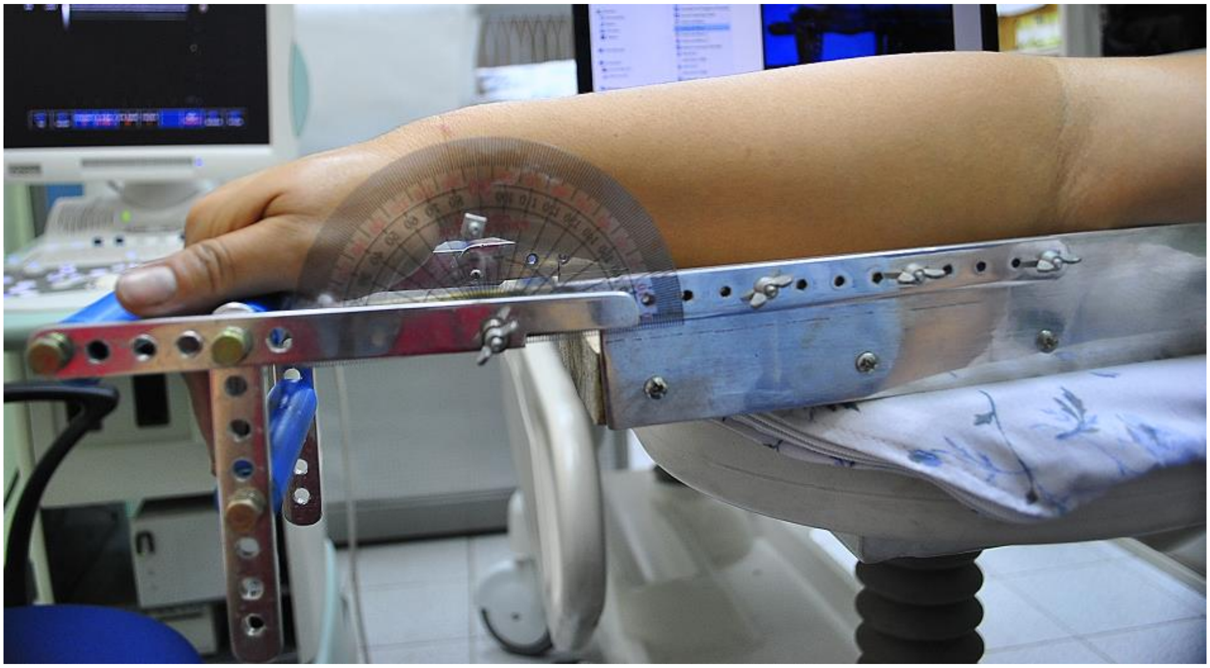

Figure 1. The mechanical test jig

Software: The MTAP in MatLab™ was developed at the Laser Light Scattering and Materials Science Laboratory of the University of South Australia (17-18). The program uses normalized cross-correlation to track a rectangular area known as a template from frame-to-frame in the video (19). The initial template is a region selected by the reader enclosing the feature of interest in the first video frame. The template is cross-correlated with the second frame of the video and the region of best match generates the next version of the template which is tracked in the subsequent frame and so on until the last frame is processed. This adaptive template approach accommodates the small changes which occur in the feature being tracked over several frames and improves the tracking greatly (17-18).

Figure 2 shows a map of a typical cross-correlation matrix. The location of the maximum is the best match between the template and the video frame. This gives the new position and thus displacement of the template.

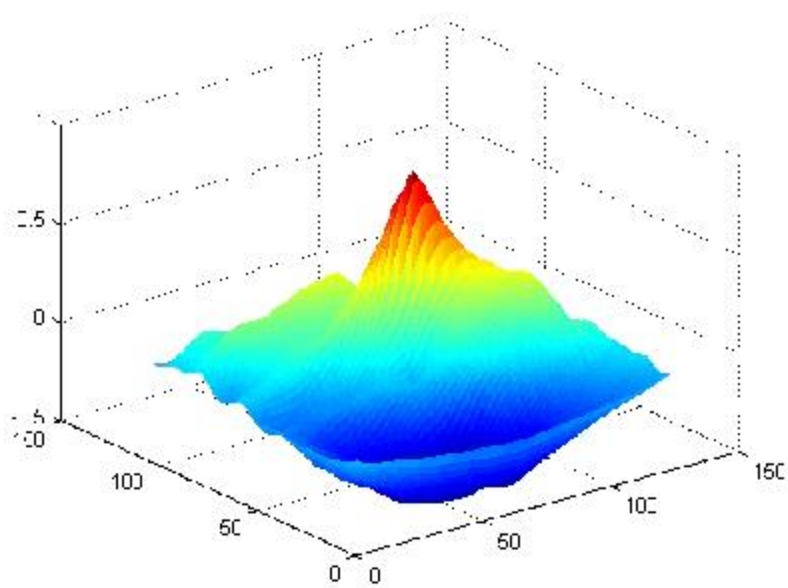

Figure 2. Cross-correlation matrix shown as surface plot

The motion of physiological structures during movement is complex and will usually consist of translational and rotational displacement and deformation. In addition the displacement may be perpendicular to the imaging plane so that, in MSUS videos, structures will apparently change shape and orientation.[17] This makes them difficult to track throughout the video sequence unless an adaptive template is used as is done here.

Even with the adaptive template, for some MSUS videos, the correlation output matrix of the MTAP may contain multiple maxima of similar magnitude resulting in ambiguous tracking as shown in Figure 3. This may occur when the feature of interest is ubiquitous or nondescript. The MTAP addresses this problem by allowing the user to limit the template displacement between adjacent frames [□x_{max}] and reduce the likelihood of jumping to a different feature during tracking. This is a legitimate and practical restriction given that the features can be observed to move only small distances between adjacent frames and the feature would be expected to be found in the neighborhood of its position in the previous frame.

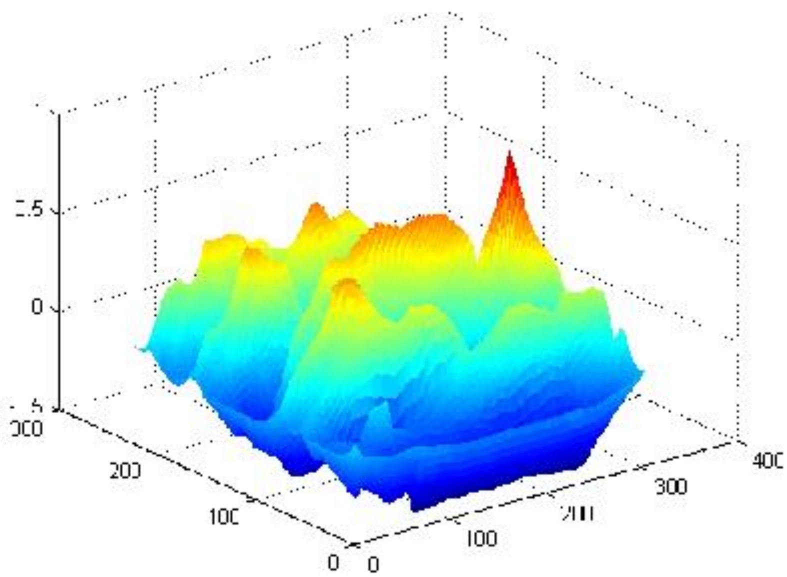

Figure 3. Cross-correlation matrix with multiple maxima

Provided that the template contains a pattern with sufficient variance and that it correlates properly [i.e. maxima in the correlation matrix exceeds 0.5, which is half of the perfect match], the accuracy of the MTAP in determining template displacement is one pixel. This determines the accuracy of the template velocity.

Study Method

*Initial Screening***:** A research assistant with four years of clinical musculoskeletal experience oriented the participants to the study, performed screening tests to determine their eligibility and recorded the presence or absence of symptoms in both elbows of the participants included in the study. Both elbows were evaluated by the research assistant using the Mill test as a screening test for LE (20).

*Standard Musculoskeletal Protocol***:** Both elbows of participants were scanned independently with the right elbow initially investigated by the two operators. The right elbow was imaged first to standardize the evaluation.

A stopwatch set at four seconds was used to coordinate the timing of the participant's active wrist flexion and start of MSUS scan. During wrist flexion, the movement of the EDC and ECRL were recorded using MSUS. Three locations were consecutively scanned under a high frequency linear transducer head as follows:

Location 1: Dorsal distal half of forearm. Here the upper edge of the transducer head was placed on the distal 1/3 of the forearm as shown in Figure 4. The transducer head was positioned parallel to the long axis of the ulna. The EDC was scanned at 1cm skin depth.

Figure 4. Placement of the transducer head on the dorsal distal half of the forearm (location 1)

Location 2: Dorsal proximal half of forearm. Here the upper edge of the transducer head was placed at the level of the upper end of the head of the radius on the proximal third of the forearm as shown in Figure 5. The transducer head was positioned parallel to the long axis of the radius. The EDC was scanned at 1 cm skin depth.

Figure 5. Placement of the transducer head on dorsal proximal half of the forearm (location 2)

Location 3: Lateral distal half of arm. Here the lower edge of the transducer head was placed immediately above the lateral epicondyle on the distal third of the arm as shown in Figure 6. The transducer head was positioned parallel to the distal aspect of the humerus. The ECRL muscle was scanned at 2.5cm skin depth.

Figure 6. Placement of the transducer head on lateral distal half of arm (location 3)

Locations 1, 2, and 3 were scanned by each operator in succession with one minute rest period between scans. This scanning procedure was repeated twice for each location by each operator.

Assessment of the Musculoskeletal Ultrasound Videos

The MSUS videos obtained by the operators from the upper extremities of the participants were assessed qualitatively and quantitatively by the reader.

Qualitative Assessment: Musculoskeletal ultrasound video image analysis using Windows Media Player

Windows Media Player was used to assess the quality of the MSUS videos. The MSUS videos with clear distinction between muscles, bones and fascia were initially evaluated to exclude the factors that hinder successful tracking of the features of interest within the EDC and ECRL [e.g., typical blur of the entire image, poor contrast of tracked structures]. These videos were the first set of images investigated.

Quantitative Assessment: Tracking the linear displacement of the ***e****xtensor carpi radialis longus and extensor digitorum communis using Motion Tracking Analysis Program:* To start tracking the movement in EDC and ECRL using MTAP, an area in the first frame of the MSUS video containing the feature of interest was selected as the template to be tracked. The template position was defined by the XY pixel coordinate of its corner as shown in Figure 7.

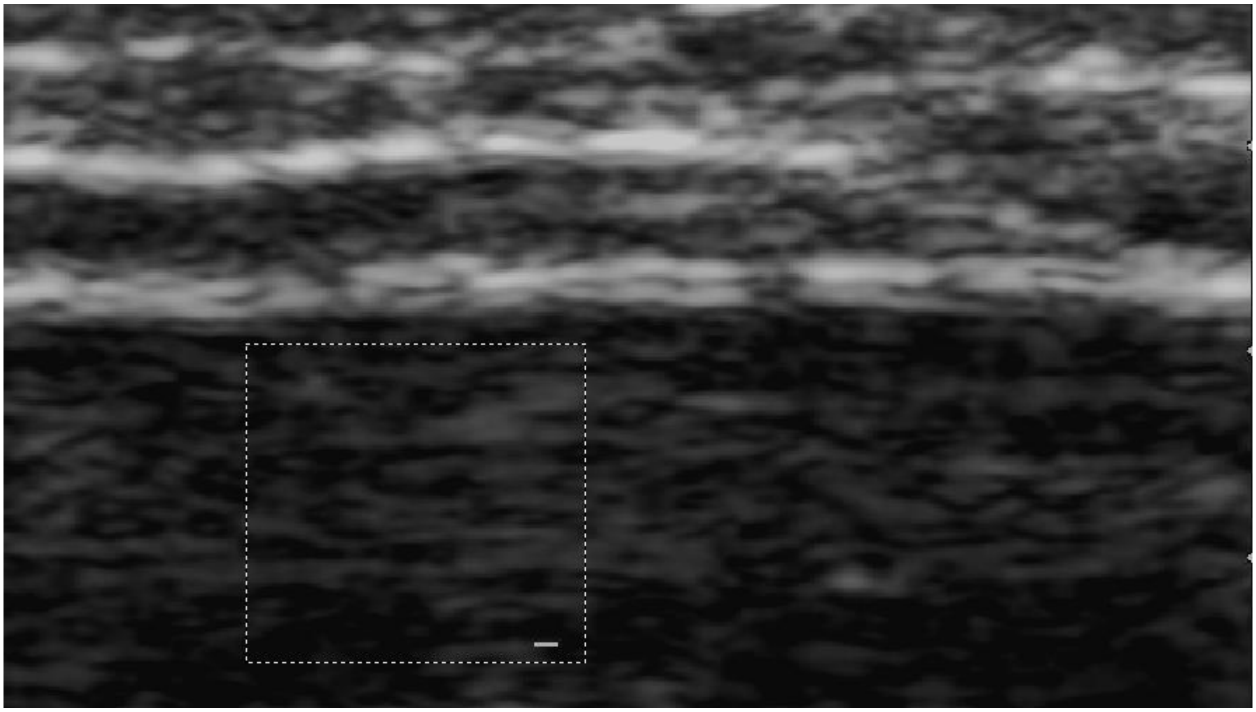

Figure 7. XY coordinate of the template.

The white arrow points to the starting XY coordinate of the tracked template. The tracked template is represented by the area contained in the box.

The MTAP tracked the template through the video as described above and the raw data for the linear displacement of EDC and ECRL were exported to Microsoft Excel™ 2010 for analysis. A list of frame-by-frame XY pixel coordinates was arranged in two columns. The link between pixels and units of length is obtained through calibration. The linear displacement of the ECRL and EDC during wrist flexion was measured along the X-axis due to the orientation of the transducer head. The linear displacement of the EDC and ECRL was computed by subtracting the initial X pixel from the final X pixel. For each video, tracking of the template was carried out three times.

Procedure to Establish Reliability of the Reader, the Sonographer, and Sonologist

Intra-tester reliability of the reader in evaluating the musculoskeletal ultrasound videos using MTAP: To determine the intra-tester reliability of the reader in measuring the movement of the EDC and ECRL using MTAP, all MSUS videos which were tracked in 2010 were re-analysed in 2012. The reader was blinded to the size of the tracked template and the results of the linear displacement of the EDC and ECRL of 2010. During re-analysis of the first set of MSUS videos in 2012, the MSUS videos were tracked four times.

Reliability of the sonographer and the sonologist: To determine the intra-tester reliability of the sonographer and the sonologist, the reader compared the results of the linear displacement of the tracked template between the first and second sets of MSUS videos that each had collected.

To determine the inter-tester reliability of the sonographer and sonologist, the first set of MSUS videos obtained by each tester was matched according to the participant's identification code, laterality of symptoms, and location. Differences in linear displacement of the EDC and ECRL were then compared.

III. STATISTICAL ANALYSES

No current studies establishing the reliability of testers in collecting MSUS images of EDC an ECRB in elbows with LE are reported. To compute for the sample size, the authors instead used the differences in the mean measurements of median nerve longitudinal slide in the wrists of individuals with carpal tunnel syndrome reported in the study of Erel et al. (2003).[21] As a result of sample size calculation using MedCalc Version 12.3.0 [MedCalc Software, Ostend, Belgium], this study was powerful enough to detect differences in longitudinal sliding of the EDC and ECRB at 80% power of 0.05.

The SE_M was used to estimate the error of the reader in measuring the linear displacement of the EDC and ECRL using the MTAP. The formula used to calculate SE_M is

$$SE_M = SD \times \sqrt{1 - ICC} \quad (1)$$

where SD is the standard deviation of differences and ICC is the intra-class correlation coefficient.

The SD was calculated from the differences in the measured linear displacement [in pixels] of the EDC and ECRL in 2010 and 2012. The ICCs were computed from the results of the measured linear displacement of the EDC and ECRL using MedCalc Version 12.3.0 [MedCalc Software, Ostend, Belgium]. The uncertainty in the total measured linear displacement of the EDC and ECRL due to the SE_M of the reader was expressed as a percentage of the measured displacement, i.e. relative uncertainty = (SE_m/average linear displacement)*100.

The intra- and inter-tester reliability of the sonographer and the sonologist in scanning the forearm was determined using the

ICC obtained using MedCalc. The ICC coefficient is a commonly used statistical measure in determining the intra-tester reliability of measurements of the same tester and inter-tester reliability of measurements obtained by two different testers. Single measures in ICC were used to obtain the intra-tester reliability of each sonographer and sonologist in scanning the linear displacement of the EDC and ECRL following a standard scanning protocol. Moreover, the average measures of the linear displacement of the EDC and ECRL of the sonographer and sonologist were determined to obtain the inter-tester reliability of both testers.

Intra-class correlation coefficients were interpreted as 0-0.2 = poor agreement, 0.3-0.4 = fair agreement, 0.5-0.6 = moderate agreement, 0.7-0.8 = strong agreement, and >0.8 almost perfect agreement.

IV. RESULTS

Participants

Six participants [three females, three males] aged 46 to 52 years [mean±SD: 49±2] with a mean duration of symptoms of nine months [minimum to maximum: 2.5 to 14 months] were included in the study. Among the 12 elbows of the six participants, only eight elbows of four participants (three with unilateral LE, one with bilateral LE) were scanned by both sonographer and sonologist due to scheduling difficulties. Both elbows of one participant were only scanned by the sonologist.

Number of Musculoskeletal Ultrasound Videos

As shown in Figure 8 there were a total of 112 MSUS video scans recorded. The sonographer scanned a total of 52 MSUS videos including 48 from eight elbows scanned twice for three locations, and four from one elbow which were discarded by the sonographer due to perceived image blurring but were viewed clearly using the Windows Media Player by the reader, and thus included in the tracking analysis. The sonologist scanned a total of 60 MSUS videos including 48 from eight elbows scanned twice for three locations and 12 from both elbows of one participant [two elbows scanned twice for three locations].

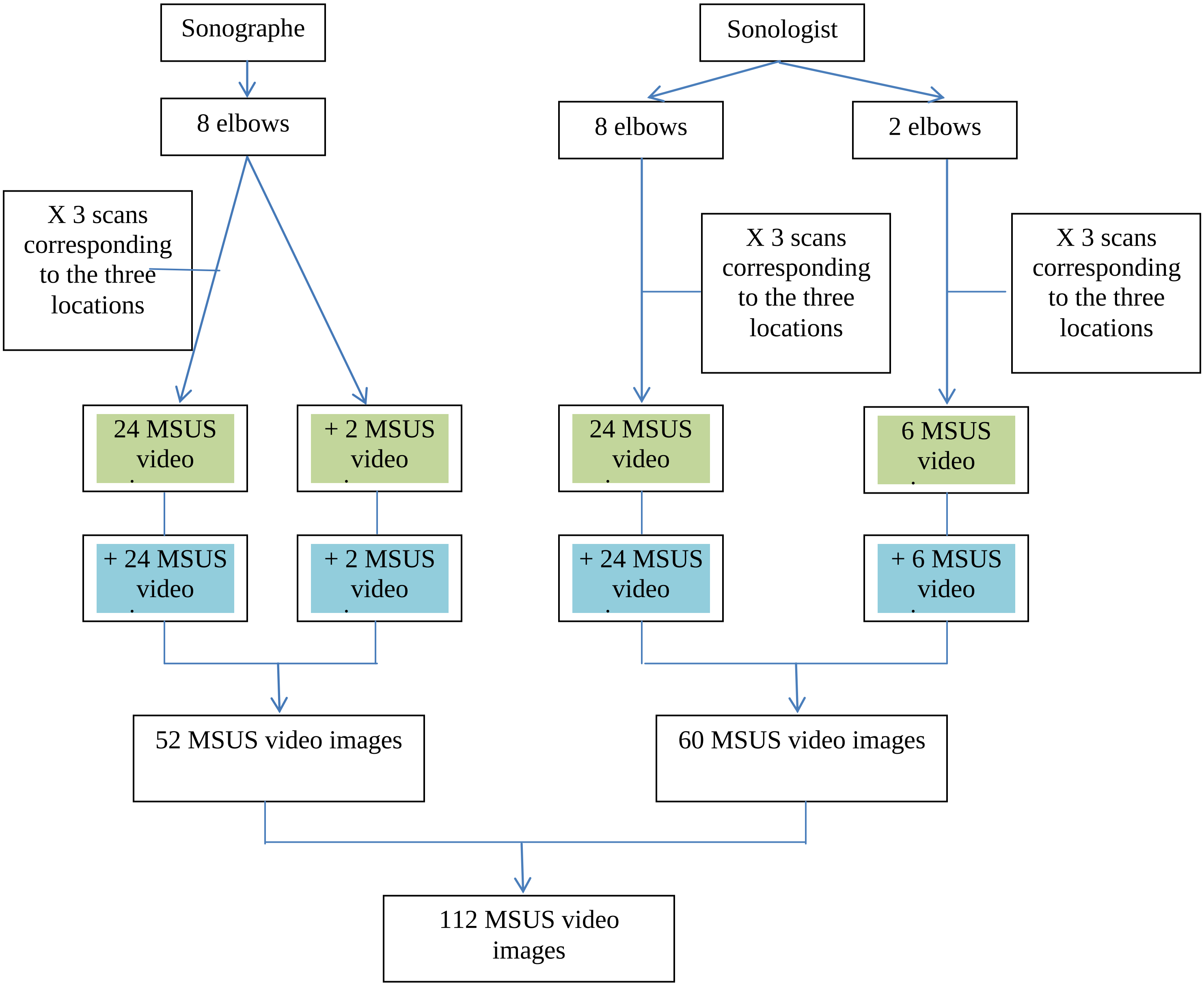

Figure 8. Flowchart of scanned MSUS images. *Key:* MSUS, musculoskeletal ultrasound

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*Details of the Musculoskeletal Ultrasound Videos***:** The size of the ultrasound image is 407 x 636 pixels, with the image in 8-bit grayscale [8 bits per pixel with 256 shades of gray]. Data were taken at 25 frames per second and a 75 frame sequence was analyzed as shown in Figure 9. The size of the template selected in the initial frame was different for each of the MSUS videos.

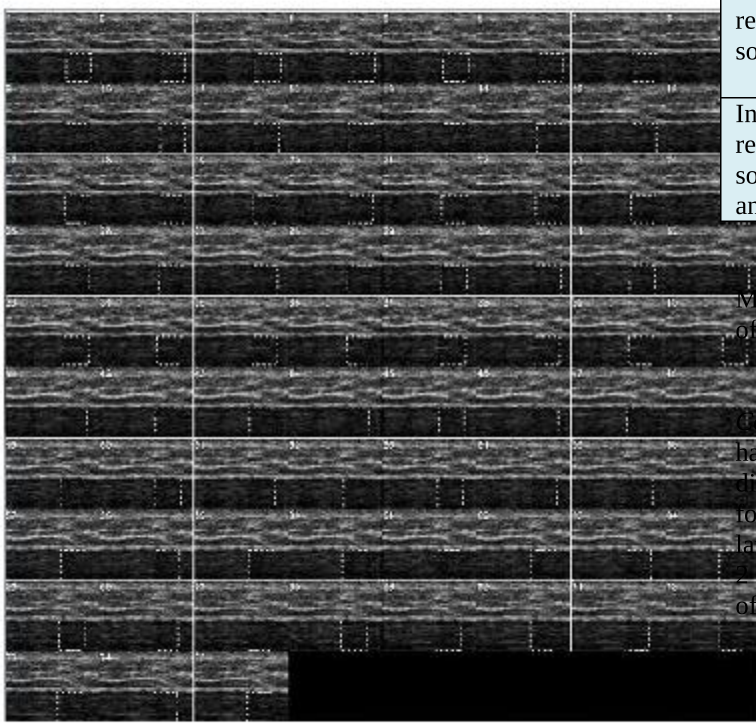

Figure 9. Seventy-five tracked templates of the Extensor Digitorum Communis in a musculoskeletal ultrasound video

*Number of Musculoskeletal Ultrasound Videos Used for Reliability Test***:** The MSUS videos with better image quality were used to compute the SE_M of the reader [53 MSUS videos] and the inter-tester reliability of the sonographer and the sonologist [20 pairs of MSUS videos]. The intra-tester reliability of the sonographer and sonologist was determined by comparing the linear displacements of the EDC and ECRL between the two sets of scanned MSUS videos. The second set of MSUS videos had poor image quality compared with the first set of MSUS videos. Table 1 lists the number of MSUS videos tracked to determine the reliability of the reader, sonographer and sonologist.

Table 1. Number of musculoskeletal ultrasound (MSUS) video images investigated

	Windows Media Player		MTAP
	Initial number of MSUS video images investigated for clarity	Number of blurred MSUS video images	Final number of MSUS video images tracked
SE_M of primary Investigator	56	3	53 pairs loc 1=18 loc 2=17 loc 3=18
Intra-tester reliability of sonographer	26	First set: 0 Second set: 6	20 pairs loc 1=7 loc 2=7 loc 3=6
Intra-tester reliability of sonologist	30	First set: 3 Second set: 8	22 pairs loc 1=8 loc 2=6 loc 3=8
Inter-tester reliability of sonographer and sonologist	Sonographer: 24 Sonologist: 24	Sonographer: 2 Sonologist: 2	20 matches loc 1=7 loc 2=5 loc 3: 8

Key: loc, location; MSUS, musculoskeletal ultrasound; MTAP, motion tracking analysis program; SEM, standard error of measurements

*Average Linear Displacement of the Extensor Digitorum Communis and the Extensor Carpi Radialis Longus***:** The reader had almost perfect agreement between the average linear displacements of the EDC muscle in the proximal dorsal half of forearm [location 2] followed by the ECRL muscle in the distal lateral half of the arm [location 3] taken in 2010 and 2012. Table 2 shows the average linear displacement of the EDC and ECRL of the upper extremities.

Table 2. Average linear displacement of EDC and ECRL in the upper extremities

Location	Read in 2010: Average Linear Displacement (in pixels)	Read in 2012: Average Linear Displacement (in pixels)
1 (EDC tendons)	88.28	92.72
2 (EDC muscle)	60.88	61.18
3 (ECRL muscle)	18.38	20.11

Key: ECRL, Extensor Carpi Radialis Longus; EDC, Extensor Digitorum Communis

*Standard Error of Measurement of the Reader in the Use of the Motion Tracking Analysis Program***:** The SE_M of the reader in measuring the linear displacement of the muscles in all three locations was 5.40 pixels. The smallest SE_M was 0.37 pixel at location 2 which has negligible influence on the measured muscular linear displacement of the EDC. The largest SE_M of 13.80 pixels was in location 1 comprising 15 percent of the average linear displacement of the EDC tendon. The SE_M in location 3 was 1.00 pixel [ECRL muscle] comprising four to five percent of the averaged linear displacement of the ECRL muscle.
Intra-tester Reliability of the Reader in the Use of the Motion Tracking Analysis Program: Considering all 53 MSUS videos analyzed in 2010 and re-analyzed in 2012, there was an almost perfect agreement in the tracking analysis of the reader [ICC=0.93, 95% CI=0.89-0.96] using MTAP with most of the agreements occurring in locations 2 and 3, as reported Table 3.

Table 3. Intra-class correlation coefficients of the primary investigator in using the Motion Tracking Analysis Program; and the sonographer and the sonologist in scanning the Extensor Digitorum Communis and Extensor Carpi Radialis Longus muscles

	Intra-tester reliability			**Inter-tester reliability**
	Primary investigator	Sonographer	Sonologist	Sonographer and sonologist
Location	Intra-class correlation coefficient (95% confidence interval)			
1	0.86 (0.67-0.95)	0.42 (-0.41 to 0.87)	0.90 (0.59 to 0.98)	0.37 (-2.68 to 0.90)
2	1.00 (0.99-1.00)	0.88 (0.46 to 0.98)	0.92 (0.42 to 1.00)	-0.69 (-15.20 to 0.82)
3	0.95 (0.87-0.98)	0.81 (0.13 to 0.97)	0.81 (0.13 to 0.97)	0.78 (-0.11 to 0.96)
Average for all three locations	0.93 (0.89-0.96)	0.65 (0.31 to 0.85)	0.88 (0.72 to 0.95)	0.58 (-0.71 to 0.83)

Key: Location 1, dorsal distal half of the forearm; Location 2, dorsal proximal half of the forearm; Location 3, lateral distal half of arm

Reliability of the Testers

Intra-tester Reliability of the Sonographer: For the 20 paired MSUS videos, there was a moderate agreement between the first and second sets of MSUS videos scanned by the sonographer with fair to almost perfect agreement found in Location 2 (EDC muscle, ICC=0.88, 95% CI=0.46-0.98).

Intra-tester Reliability of the Sonologist: For the 22 paired MSUS videos, there was a moderate agreement between the first and second set of MSUS videos of the sonologist with fair to almost perfect agreement noted in location 1 [EDC tendons, ICC=0.90, 95% CI=0.59-0.98] and location 2 [EDC muscle, ICC=0.92, 95% CI=0.42-1.00].

Inter-tester Reliability of the Sonographer and the Sonologist: For the 20 matched MSUS videos [from the first set of MSUS videos] of the sonographer and the sonologist, there was a wide range of agreement ranging from chance to excellent in the matched MSUS videos between the testers [ICC=0.58, 95% CI=-0.71-0.83].

V. DISCUSSION

This is the first study to report on the standard error of measurement and reliability of using a MTAP in measuring the linear displacement of the EDC and the ECRL in individuals diagnosed with LE. The study's findings were: 1. the reader was most reliable in measuring the linear movement of the EDC muscle [location 2] using the MTAP, 2. the scanning of the linear movement of the EDC muscle in location 2 twice in succession by the sonographer or the sonologist showed moderate to excellent reproducibility of the MSUS videos, and 3. the agreement in the linear displacement of EDC and ECRL on MSUS videos collected by the sonographer and sonologist was variable.

The standard error of measurement of the reader depends on the re-identification of the XY coordinate of the previously tracked template and the contrast of the MSUS videos. The re-identification of the XY pixel was challenging due to the absence of a grid ruler in the MTAP and the absence of an identifiable bony landmark on the template in location 3. In lieu of the grid ruler, the right border of the window frame of the MTAP was used as a guide by the reader in re-identifying the XY coordinate of the EDC muscle in location 2. This decreased the reader error in re-identifying the XY coordinate resulting in the lowest SE_M of 0.37 pixel. Although the lateral epicondyle was used as a bony landmark for location 3, the angled orientation of the ECRL and the central location of the XY coordinate on the MSUS video frame made it difficult for the reader to locate the previously used XY coordinate. The re-identification of the XY coordinate in Location 1 was most challenging. The MSUS videos in Location 1 had poor contrast compared with the MSUS videos in Locations 2 and 3. There were no bony landmarks or grid ruler available. The complex movement of the EDC tendon between the skin and ulna as terminal wrist flexion approached may have been the underlying cause of the blurring of the videos. These factors contributed to the highest SE_M of 13.80 pixels of the reader in analyzing the videos in Location 1.

The sonographer and sonologist demonstrated moderate to perfect agreement in capturing the linear displacement of the EDC in Location 2 between the two successive MSUS videos. This was secondary to the minimal variation in the characteristics and movement of the EDC muscle in the proximal section of the forearm during scan. Given that the depth of scan of EDC in Location 2 is set at 1cm skin depth, the thickness of the EDC in Location 2 was almost uniformly reproduced in the next MSUS videos. During the scan when the wrist was flexing, there was minimal vertical displacement of the EDC muscle, and blurring of the MSUS videos resulting in fewer extraneous factors that would have influenced the reproducibility of the MSUS videos. Reproducing the MSUS videos in Location 3 proved to be challenging despite the conscious effort of the testers to ensure the static position of the transducer head on the distal lateral aspect of the arm. The wrist flexion movement could have caused a difference in the position of the ECRL [Location 3] during scan. The ECRL may not have moved linearly under the static transducer head which could mean tracking of structures other than the ECRL.

The wide range in agreement [poor to excellent] between the first and second set of videos of the sonographer in Location 1 may be due to the characteristics of the middle EDC tendons and their non-linear movement during wrist flexion. In contrast to the ultrasound videos collected by the sonologist, the sonographer deviated from the scan protocol and scanned the EDC tendons running exactly at the centre of the wrist. These

EDC tendons were more mobile than the tendons found at the borders of the wrist (22). Moreover, the middle EDC tendon movement could have been influenced by the repetitive wrist flexion movement during scans releasing them and thus yielding greater variations in the linear displacement of the EDC tendons. Despite the use of a standard scanning protocol for EDC and ECRL, there was a possibility of obtaining two significantly different linear muscular displacements from two different testers. Although our study controlled for variables such as MSUS machine and mechanical test jig used, time of day of scan, and standard protocol, factors such as differences in the experience in MSUS use of the sonographer and sonologist, number and timing of execution of wrist flexion, time in between MSUS scans, differences in the angle of tilt and pressure used on the transducer head, difference in the placement of the transducer head and mechanical characteristics of the muscles and tendons to movement caused varying agreement in the MSUS videos obtained by the sonographer and the sonologist.

The MTAP can be a reliable tool in measuring the linear displacement of EDC muscles in the proximal dorsal half of the forearm. The uniform characteristics of the structures under investigation during movement, such as found in the EDC muscle in Location 2, and scanning twice in succession are likely to increase the reproducibility of the MSUS videos. The MSUS scan procedures which are open to varying interpretation [such as that used in scanning the ECRL in Location 3] should be clarified prior to the implementation of the study.

Implications for Research

There is a need to standardise the protocol in scanning for the movement of the EDC tendon in Location 1. A specific point on the dorsum of the wrist to place the transducer head to scan the EDC tendon should be agreed prior to scanning.

A modern system which automatically puts the MSUS machine in scan mode once wrist flexion starts addresses the time lag that occurs in a manual and operator dependent system. A visual display of wrist flexion will provide an additional cue to verbal promptings, thus, improving the timing for initiation of wrist flexion.

Limitations of the Study

The study did not trace the scanned EDC and ECRL from their origin which could have further enabled the sonographer and sonologist in identifying these structures. Instead, the guide used by the testers in identifying the EDC and ECRL was based on descriptions of the muscles origin and insertion as found in the studies by Bunata et al. (8), Cohen et al. (23), Snell (24), Kutsumi et al. (22,25), and Greenbaum et al. (26).

The study used a system where the reader coordinated the synchronous initiation of wrist flexion movement and pressing of the scan button by the tester. The time lag between the verbal prompting of the reader and the initiation of the wrist flexion movement, the verbal prompting of the reader and the pressing of the scan button by the tester, and the initiation of the wrist flexion movement and the pressing of the scan button by the tester could have influenced the reproducibility of the MSUS videos. This time lag was not quantified in this study. The extent to which time lag affected the reliability of the testers was not determined in this study. Moreover, the non-fixed shoulder and elbow joints could have influenced the reliability of the testers and was not assessed in this study.

Due to unavoidable errors in scanning such as the transducer head slipping off the skin while the wrist was flexing, a number of patients had to repeat the wrist flexion movement more than six times per limb. This could have influenced the extensibility of the forearm extensor muscles thus affecting the linear displacement of the EDC [muscle and tendon] and ECRL [muscle].

VI. CONCLUSION

Using the MTAP, the reader was most reliable in determining the linear muscular displacement of the EDC in the proximal dorsal half of the forearm of participants with at least one upper extremity with LE. Additionally, each of the sonographer and sonologist was reliable in scanning the EDC in the proximal forearm scanned twice in succession. This established reliability of the reader and the testers is important in characterising the mobility of the EDC muscles which may potentially clarify its role in the genesis of pain in elbows with LE.

CONFLICT OF INTEREST

We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated and, if applicable, we certify that all financial and material support for this research and work are clearly identified in the manuscript.

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FIGURE LEGEND

Figure 1. The mechanical test jig

Figure 2. Cross-correlation matrix shown as surface plot

Figure 3. Cross-correlation matrix with multiple maxima

Figure 4. Placement of the transducer head on the dorsal distal half of the forearm [Location 1]

Figure 5. Placement of the transducer head on dorsal proximal half of the forearm [Location 2]

Figure 6. Placement of the transducer head on lateral distal half of arm [Location 3]

Figure 7. XY coordinate of the template. The white arrow points to the starting XY coordinate of the tracked template. The tracked template is represented by the area contained in the box.

Figure 8. Flowchart of the procedure for obtaining musculoskeletal ultrasound images

Figure 9. Seventy-five tracked templates of the extensor digitorum communis in a musculoskeletal ultrasound video.