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Diagnostic Value of Musculoskeletal Ultrasound in Acute and Chronic Lateral Epicondylalgia

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ABSTRACT

Introduction: The literature suggests that abnormal sonographic findings of the common extensor origin (hypoechogenicity, neovascularity, calcifications, irregular margin, presence of adjacent fluid, irregular fibrillar pattern, thickness, tear) and of the lateral epicondyle (cortical irregularities) can be used to confirm the presence of Lateral Epicondylalgia (LE) in elbows which have been initially diagnosed using the clinical diagnosis for LE. The association of these abnormal sonographic findings and the initial clinical diagnosis for LE were studied. **Methodology:** The participants were recruited in Metro Manila (Philippines) through advertisements and referral by doctors and physiotherapists. LE was determined if participants reported lateral elbow pain on one elbow which was replicated by any of the Cozen's, Mill's, or Maudsley's tests. Acuity of elbow symptoms was determined using six weeks since symptom onset as the time differentiating acute from chronic LE. A prospective blinded sonographic assessment of both elbows of participants was performed using a valid and reliable scanning protocol. **Results:** Fifty-one participants provided 55 symptomatic and 46 asymptomatic elbows (one elbow ineligible due to congenital shortening). Duration of elbow pain ranged from a day (acute) to 36 months (chronic). The hypoechogenicity of the common extensor origin was moderately associated with acute LE (sensitivity=67%, specificity=38%) and strongly associated with chronic LE (sensitivity=81%, specificity=64%). The calcifications of the CEO were found to be significantly associated with acute LE (DOR: 14.62) and chronic LE (DOR: 7.26) with $p<0.05$. **Conclusion:** Sonographic measures of hypoechogenicity and calcifications of

the common extensor origin may complement the findings from the elbow provocation tests in confirming a diagnosis of acute or chronic LE.

INTRODUCTION

Lateral Epicondylalgia (LE) is the most common cause of pain in the lateral aspect of the elbow affecting the common extensor origin (CEO).[1] This condition is generally more common in individuals between 35 to 60 years of age albeit it can occur at any age.[2-5] The incidence of LE in medical consultation ranges from 0.3 to 1.1% and in the working population from 2 to 4%.[6] The mean number of lost workdays per year from elbow pain (including LE) is 2.3 to 3.9.[7]

A clinical diagnosis for LE is dependent on reports of pain on the lateral epicondyle, lateral epicondylar tenderness, and positive response to any of the three provocation tests, namely the Cozen's, Mill's, or Maudsley's test.[8-10] These provocation tests are designed to stress the CEO and replicate the patient's reports of lateral elbow pain.[11] These provocation tests are easily applied on elbows of patients and are commonly used in clinical and research settings.[12] Despite their practical use, there is no reported diagnostic validity in the current literature that is specific to each of these provocation tests. Additionally, there is limited evidence on their ability to identify specific elbow structures related to lateral elbow pain.[11]

The poor diagnostic validity of Cozen's, Mill's, and Maudsley's tests may be associated with less than adequate physiotherapy treatment outcomes for LE, as without a sound understanding of which structures are involved, physiotherapy treatment is likely to be non-specific.[11,13] Consequently, suboptimal treatment outcomes are likely associated with workdays lost and residual symptoms.[13]

The search for better clinical diagnosis of LE is associated with the increased use of musculoskeletal ultrasound (MSUS).[11] Improvements in MSUS equipment and in frequencies of transducer heads (5 to 17 MHz) have yielded better quality ultrasound images.[14] Better resolution on echotexture of muscles, tendons, and bones in ultrasound images are associated with improved diagnostic validity of MSUS in detecting the presence of LE.[15] Additionally, real-time images demonstrating changes in size of nerves, tendons, and bones and the relationship of elbow structures are likely to improve the diagnostic validity of MSUS in the determination of LE.[15]

Musculoskeletal ultrasound (MSUS) and Magnetic Resonance Imaging (MRI) are diagnostic equipment that demonstrate soft tissue contrast of anatomical structures within elbows containing abnormalities.[15] Of the two diagnostic equipment, the MSUS is more practical to use in the clinics as it is more cost-effective than the MRI.[16] The cost-effectiveness of MSUS has led to its increased use in healthcare practice since 2001.[12,17,18-20] Despite MSUS not being as sensitive as MRI, its specificity is comparable with MRI. According to Shahabpour et al., MSUS might be adequate for diagnosing LE and MRI may be reserved for patients with symptoms whose MSUS findings are normal.[16]

Appendix 1 reports the common abnormal MSUS findings in elbows with LE namely:

- hypoechogenicity,
- neovascularity,
- calcifications,
- thickening,
- fibrillar changes,
- adjacent fluid, and
- tears of CEO and lateral epicondyle irregularities.[12,17,21,22]

Hypoechogenicity of the CEO are ruptured collagens corresponding to histological findings of scar tissue with marginal areas of degeneration in the CEO.[15,23,24] Calcifications of the CEO are irregularly-shaped foci of hyperechoic areas within the CEO, reflecting severity of the degeneration process.[15,18,25,26] Neovascularity of the CEO is intratendinous hyperemia detected as colour-flow signal indicating failed attempts of the CEO to heal itself after repetitive elbow activities, reflecting inadequate blood supply in the CEO.[27]

Lateral Epicondylalgia Based on Acuity of Elbow Symptoms

LE is generally classified into acute and chronic stages based on the duration of lateral elbow pain.[28] Acute LE is described by patients as feeling of something "giving way" within the elbow during traumatic and forceful activities.[28,29] It is characterised by tenderness and swelling of forearm extensor muscle with microscopic injuries within the CEO.[28,30,31] Conversely, chronic LE

develops over time after repetitive and forceful handgrip activities. In chronic LE, the intensity of pain and its associated disability are less when compared to acute LE.[28,30]

As reported in Appendix 1, the consensus in the literature as to the definitive cut-off point in the duration of elbow symptoms differentiating acute from chronic LE is lacking, as evidenced by the time frames given in the following studies: 1 week, 3 weeks, 6 weeks, and more than 4 weeks.[22,31-37] Archambault et al and Soslowsky et al reported the presence of inflammatory markers in as early as six weeks in the acute stage of tendon injuries.[38,39] Despite this, there is no consensus among authors on the use of the descriptors of acute or chronic LE. Additionally, figures on the diagnostic validity of MSUS findings specific to acute LE have not been clearly identified and reported in the current literature.

Our study sought to determine the diagnostic validity of eight abnormal MSUS findings of the CEO (hypoechogenicity, neovascularity, calcifications, irregular margin, presence of adjacent fluid, irregular fibrillar pattern, thickness, tear), and one MSUS finding of the lateral epicondyle (cortical irregularities) to confirm the presence of LE in elbows which were initially diagnosed with LE using a clinical diagnostic approach. Based on the acuity of elbow symptoms, using six weeks as time differentiating acute from chronic LE, we investigated the association of these abnormal MSUS findings and the clinical diagnosis of LE.

METHODOLOGY

Ethics

This research was approved by the Ethics Review Board of the University of Santo Tomas (UST) (Ethics approval: IRB-AP210-D-LEPS) and the Human Research Ethics Committee of the University of South Australia (Ethics approval: 22328).

Setting

Physiotherapy Skills Laboratory and the Department of Physical Medicine and Rehabilitation of UST.

Study Population

Volunteer participants were recruited from January 2011 to September 2011 via a comprehensive campaign using advertisements, flyers, and social networking sites in a wide-ranging reference population reflecting private and public hospitals, private clinics, sport clubs, marketplace, factories, health centres, and schools in Manila, Philippines. Participants were also accepted from consecutive referral by doctors and by physiotherapists in Manila. This approach was taken because there was no available comprehensive register of individuals with LE from which to recruit participants randomly.

To be eligible for study inclusion, participants needed to report pain over the lateral elbow area regardless of duration of symptoms. Potential participants who reported pain over the lateral epicondyle or in the regions five centimeter proximal and five centimeter distal to the lateral epicondyle were eligible to participate in the study.[8-9] Potential participants were excluded if they had current general body malaise, current diagnosis of cancer, previous or current fractures in arm/forearm/wrist, elbow osteoarthritis, recent blunt elbow trauma, cervical radiculopathy, peripheral neuropathy, stroke, previous surgery to elbow, or were pregnant.

Reliability of the Examiners

The sonologist had 20 years of practice in rehabilitation medicine and had been using MSUS for the past four years. The sonologist's reliability in using MSUS on the elbow region was established through comparison with an expert Australian sonographer who had 20 years of experience in the use of MSUS.[40] The sonologist and sonographer demonstrated perfect agreement (Kappa=1.0) on finding irregularities on the lateral epicondyle; moderate agreement (Kappa=0.60) on finding neovascularity in the CEO; and fair agreement on finding calcifications within the CEO (Kappa=0.53) and fluid around the CEO (Kappa=0.25).[40] A research assistant, who was trained for more than three years in musculoskeletal assessment, performed the clinical examination.

Study Processes

Initial Screening

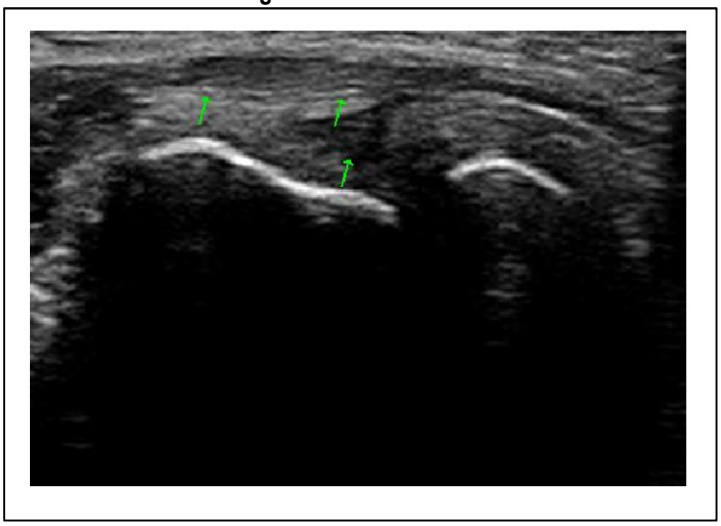
The purpose and mechanics of the study were explained to participants, and they signed a consent form. The provocation examinations of Cozen's, Mill's, and Maudsley's tests were performed by the research assistant (working independently of the other researchers) by testing both elbows of consenting and eligible participants. Participants who had reproduction of pain in the lateral elbow by any of the three tests were classified as having LE. Elbows without pain were classified as asymptomatic. The history and activities aggravating the participants' lateral elbow pain were recorded.

Imaging and Interpretation

A prospective blinded MSUS assessment by the sonologist was performed on both elbows of consecutive participants with LE using an ESaote MyLab 40 Family Ultrasound machine (ESaote Asia Pacific Diagnostic Private Limited) with a multi-frequency broadband transducer (up to 18 MHz). Because of a lack of time and funding, asymptomatic subjects were not imaged. The sonologist was blinded to the elbow with LE. An imaging protocol in obtaining optimal MSUS images of the CEO and lateral epicondyle that is valid and reliable was used in this study.[40]

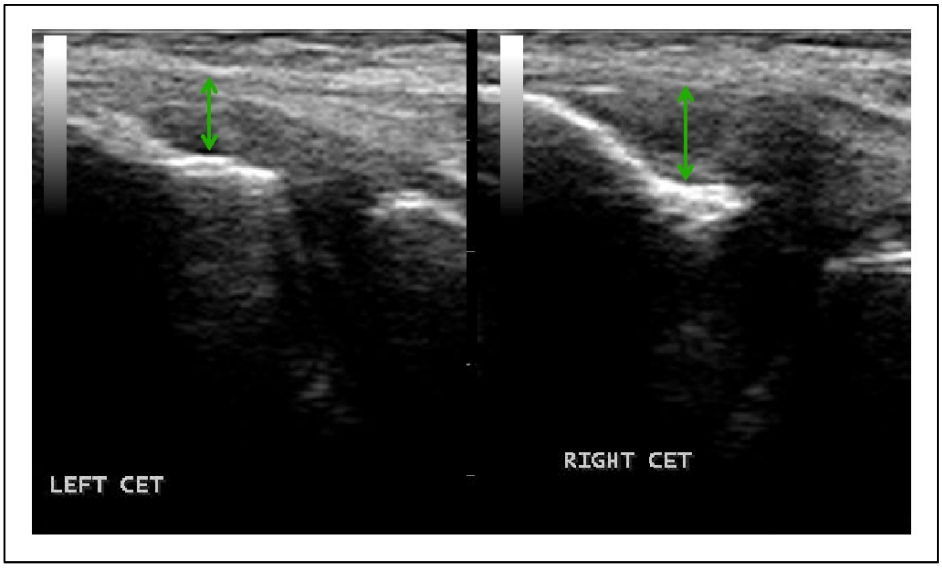
Following the processes outlined in the research summarised in Appendix 1, MSUS measures of hypoechogenicity, neovascularity, calcifications, adjacent fluid, irregular fibrillar pattern, tendon thickness, and tear were taken, as well as irregularities on the margin of the CEO.[12,17,21,22] The presence of a tear was indicated by a longitudinal split within the CEO (Figure 1). However, the sonologist in this study did not determine the extent of the tear. The CEO thickness was determined as "enlarged" if there was a 10% difference compared with the opposite side, as suggested in the studies of du Toit et al and Connell et al (Figure 2).[12,17] To confirm the abnormal MSUS changes in the CEO and lateral epicondyle, longitudinal and transverse scans were obtained. For each participant, the provocation tests and the MSUS examination occurred within two hours, reducing the potential for the condition to change (maturation bias).[12,41]

Figure 1. Musculoskeletal Ultrasound Findings of the CEO of a 49-Year Old Female Participant with Right LE



The upper green arrows indicate hyperechoic changes within the CEO. The lower green arrows indicate presence of tear within the CEO. Key: CEO, common extensor origin

Figure 2. CEO Thickness of a 40-Year Old Female Participant with Right LE



The CEO in the right elbows with LE was thicker compared to the CEO in the left elbow without LE. Key: CEO, common extensor origin; LE, Lateral epicondylalgia

Reference Standard

The reported presence of lateral elbow pain replicated by any one of the Cozen's, Mill's, or Maudsley's tests was used as a reference standard in diagnosing LE in this study. These uncomplicated provocation tests were commonly used in the clinical practice and research studies.[12]

Statistical Analysis

The clinical diagnosis of LE, as defined by reproduction of pain by at least one provocation test, was the reference standard. The six week time point was used to differentiate acute from chronic LE. The diagnostic validity was calculated using data grouped into cells A-D similar to Table 1. Each MSUS finding was compared for case LE elbows and non-LE elbows. Cell A reports on true positive findings, and cell D reports on true negative findings (as determined by agreement by both diagnostic tests). Cells B and C report on false positive and false negative findings, respectively.

Table 1. 2x2 Table for Abnormal MSUS Findings and Clinical Diagnosis of Lateral Epicondylalgia

	LE (+)	LE (-)
MSUS findings (+)	A	B
MSUS findings (-)	C	D

Key: A, True Positive; B, False Positive; C, False Negative; D, True Negative; LE, Lateral epicondylalgia; MSUS, musculoskeletal ultrasound; (+), positive; (-), negative

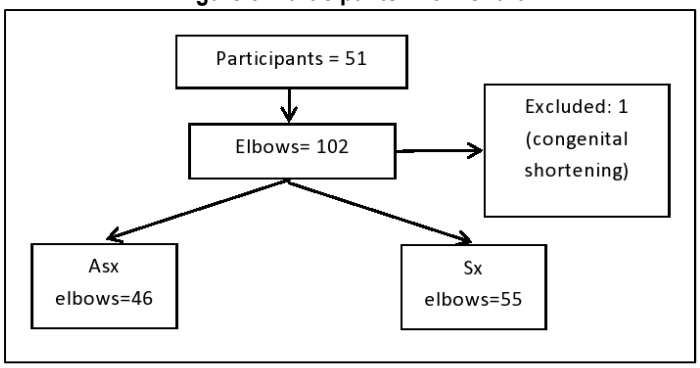
The diagnostic validity was determined using MedCalc Version 11.3.0 (MedCalc easy-to-use statistical software, 2012-2013).[42] In detail, calculations of specificity, sensitivity, likelihood ratios, predictive values and diagnostic odds ratios were determined using the following formulae:[42]

Sensitivity= A/(A+C)
Specificity=D/(B+D)
Positive predictive value=A/(A+B)
Negative predictive value=D/(C+D)
Positive likelihood ratio=A/(A+C)/(B/(B+D))
Negative likelihood ratio=(C/(A+C)/(D/(B+D)
Diagnostic odds ratio= (A/C)/(B+D)

RESULTS

From January 2011 to September 2011, fifty-four participants (39 female, 15 male) aged between 15 to 66 years (mean (SD): 41(13)) were included in the study. Three participants could not participate in the MSUS scan because of scheduling difficulties. Of the 51 available participants (102 elbows, 38 female, 13 male), one elbow was excluded from testing due to congenital shortening and flaccidity. Of the 101 available elbows, 55 elbows had LE and 46 elbows had no LE (Figure 3). Of the 55 symptomatic elbows, 49 were on the dominant side (43 on the right, four on the left, and one participant was ambidextrous).

Figure 3. Participants' Flow Chart



The participants had lateral elbow pain ranging from 1 day to 36 months, affecting 47 of the dominant elbows. Acute LE was experienced by 24 participants (43.6%) and chronic LE by 31 participants (56.4%). No significant difference ($p>0.05$) in age between the acute and chronic LE groups was noted. Within both acute and chronic groups, women predominated. Table 2 reports the characteristics of the participants and elbows examined in this study.

Table 2. Characteristics of The Participants

	Acute (current LE pain < 6 weeks)			Chronic (current LE pain > 6 weeks)		
	Total	Male	Female	Total	Male	Female
Number of participants	23	5	18	29	8	21
Age (in years) (mean, min-max)	40.8 (15 to 64)	40.6 (20 to 56)	40.8 (15 to 64)	42 (20 to 66)	41 (21 to 66)	42 (20 to 57)
Duration of elbow pain (in months) (mean, min-max)	0.46 (0.03 to 1.32)	0.49 (0.03 to 1)	0.45 (0.03 to 1.32)	6.7 (2 to 36)	7.3 (2 to 36)	6.5 (2 to 33)
Number of symptomatic elbows	24	5	19	31	8	23
Number of asymptomatic elbows	21	5	16	25	8	17
Dominant side affected Right Left	23 20 3	5 4 1	18 16 2	24 23 1	8 8 0	16 15 1
Number of participants whose bilateral elbows were affected	1	0	1	3	0	3

Key: LE, lateral epicondylalgia

Appendix 2 reports the estimates of diagnostic validity and confidence intervals of the nine abnormal MSUS measures for acute and chronic LE. Hypoechogenicity and calcifications of the CEO were the most useful predictors of acute and chronic LE. Hypoechogenicity of the CEO was the strongest predictor of LE, although it was better at predicting chronic rather than acute LE (Sns: 81% chronic, 67% acute; DOR: 7.41 chronic, 1.52 acute). Applying a high measure of specificity (of at least 80%), all other MSUS measures were strongly specific for acute LE except for hypoechogenicity of the CEO, and all MSUS measures were strongly specific for chronic LE except for hypoechogenicity of the CEO and cortical irregularities of the lateral epicondyle. Moreover, calcifications of the CEO was found to be significantly associated with acute LE (DOR: 14.62) and chronic LE (DOR: 7.26) with $p<0.05$. No adverse effects with either MSUS or clinical examination were reported.

DISCUSSION

This study reports on the diagnostic validity of abnormal MSUS findings in elbows with acute or chronic LE. MSUS measures, particularly hypoechogenicity and calcifications of the CEO, provide objective information that is relevant for both acute LE and chronic LE.

Hypoechogenicity of the CEO appears to be a stronger feature of chronic LE [Sns: 81 (64 to 91)] than acute LE [Sns: 67 (46 to 82)], reflecting a chronically overused tendon.[24] An overused CEO may be associated with weakening of the extensor carpi radialis brevis (ECRB) and extensor digitorum communis (EDC) due to suboptimal repetitive contraction of these muscles, preventing the painful sensation at the elbow that accompanies handgrip in elbows with LE.[43] Despite that calcifications are common features of chronic tendon degeneration, calcifications of the CEO are more significantly associated with acute LE (DOR: 14.62) than with chronic LE (DOR: 7.26). Its presence may be an initial attempt of the body to cope with stress by converting soft tissue structures to bony structures, implying the need to stop stressful handgrip activities as soon as pain is reported.[23] The formation of calcifications may be an immediate response of the CEO to stress created by the contracting forearm extensor muscles in the elbow. It is part of the CEO tissue remodeling process that occurs in less than six weeks of injury. Calcifications may reflect the body's attempt to functionally adapt to the mechanical load created by repetitive and forceful handgrip activities.[44]

The hypoechogenicity of the CEO has the lowest specificity (64%) compared to the specificities reported in other studies, as shown in Appendix 1. The lower specificity reported could be secondary to the sole inclusion of non-LE elbows of case participants. Similar to our study, Struijs et al (2004) investigated the non-LE elbows of subjects with unilateral LE and registered

the lowest specificity among the published studies with 25 or more participants (Appendix 1).[45] This resemblance in results suggests that there may be MSUS presentations in non-LE elbows of case participants which may be typical to them compared to those seen in non-symptomatic elbows of healthy subjects.

Considering the significant associations between hypoechogenicity of the CEO, calcifications of the CEO, acute LE, and chronic LE, the replication of lateral elbow pain through the provocation tests should not be singularly used in diagnosing LE. Muscle fatigue or soreness may cause lateral elbow pain which may be replicated by Cozen's, Mill's, or Maudsley's tests, thus potentially mimicking LE. To prevent this inaccurate diagnosis, the involvement of the CEO as determined by the MSUS, should complement the findings of the provocation tests used in diagnosing LE. Considering that MSUS is a simple, objective, inexpensive, and non-invasive way of confirming LE, the authors propose that MSUS presence of hypoechogenicity and calcification of the CEO be included in the diagnostic criteria for LE. Additionally, the presence of hypoechogenicity of the CEO as a valid diagnostic indicator for presence of chronic LE corroborates with the diagnostic validity reported for chronic LE in the systematic review by Dones et al (2014) [Sensitivity: 0.64 (0.56 to 0.72)] and specificity [Specificity: 0.82 (0.72 to 0.90)].[14] The current study further reports that the hypoechogenicity of the CEO is likewise a valid diagnostic indicator for presence of acute LE.

MSUS Findings and Physiotherapy Regimen

Considering that hypoechogenicity of the CEO may likely be associated with weakening of the CEO, we suggest graded eccentric exercise.[43] In the study of Croisier et al, 46 patients with chronic LE have received eccentric training exercises of the forearm wrist extensors, which resulted in a significant reduction of pain intensity, an absence of strength deficit on the involved side, an improvement of the tendon MSUS image, and marked improvement in disability status.[46] In a study by Martinez-Silvestrini et al, eccentric exercise improved pain-free grip strength and functional independence of 27 participants without causing any worsening of elbow symptoms.[47]

Considering that calcifications of the CEO are associated with acute LE and chronic LE, aggressive resistance exercises of the forearm extensor muscles should be avoided as these can potentially worsen symptoms associated with the calcifications of the CEO. Physiotherapy treatment such as forearm bracing, splints, taping, and adjusting handgrip size are suggested.[48-54] Forearm bracing compresses the forearm extensor muscles, which is assumed to de-load the CEO of stress.[54] Grimmer-Somers et al recommended the use of forearm bracing and taping as off-the-shelf management for LE.[51] Adjusting handgrip size for optimal grip reduces the muscular force required for gripping a tool, protects the underlying elbow joint structures, and reduces the risk of developing cumulative trauma associated with repetitive tasks requiring high hand grip forces.[52,53]

The results of this study were based on what we believe to be a wide representation of the general population with lateral elbow pain in Manila, Philippines. Participants for this study were recruited from a large reference population in an attempt to obtain broad representation of LE across a range of sectors in Manila, in the absence of a population register. The majority of the participants was self-referred and came directly from places outside health care institutions. For economic reasons, many of these participants preferred not to take leave from work for treatment or to consult a rehabilitation doctor despite the presence of their LE. This sample therefore represents a population of LE sufferers that are potentially underreported in the traditional medical literature.

Limitations of the Study

The non-LE elbows were compared to the LE elbows of case participants using MSUS measurements. A decision was made at the time that for pragmatic reasons (time and resources), MSUS studies would not be undertaken on non-symptomatic elbows of healthy subjects. This may be perceived as a limitation in our study. The non-LE elbows of the participants in our study may not mirror the non-symptomatic elbows of subjects diagnosed as not having LE. Moreover, similarity between sides within an individual has been reported as a confounder when the non-LE side has been used as the "control."[55] However, as this study specifically compared the diagnostic validity of MSUS finding with positive responses to Cozen's, Mill's, and Maudsley's tests, we believe that we took the most appropriate sampling approach. .

The intra-tester and inter-tester reliability of the sonologist was not tested in determining the presence of tear and thickness of the CEO, which may have resulted in measurement errors. Although the reliability of our sonologist is comparable to a skilled sonographer with 20 years of experience in the use of MSUS, the operator-dependent characteristic of MSUS use may limit the external generalizability of the results for CEO thickness and tear.

There is certainly a risk of self-selection bias in this study. However our sampling frame sought to include individuals who may not have been represented in the earlier published studies where recruitment occurred only in the treatment clinics and seen by health care professionals.[12,17,22]

IMPLICATIONS FOR PRACTICE

Currently, the clinical diagnosis of LE is based on the use of provocation tests (Cozen, Mill, Maudsley) which are both gross and subjective. This study confirms the diagnostic value of incorporating MSUS measures of hypoechogenicity and calcifications of the CEO when objectively confirming the presence of LE. We suggest that any elbow which is clinically diagnosed with LE, of any duration, should be sonographically scanned to identify the soft tissue abnormality in the CEO. Knowledge of these MSUS results would guide healthcare professionals in designing therapeutic regimens conducive to CEO healing and potentially addressing in some way the heavy economic burden due to workday loss and residual impairments in LE elbows.

IMPLICATIONS FOR RESEARCH

Future studies recruiting participants from a comprehensive database (i.e. central registry for musculoskeletal complaints) should be conducted to compare the MSUS findings between healthy elbows of subjects without LE with elbows diagnosed with LE. Particularly, this study should establish that the non-LE elbow of a subject with unilateral LE had similar MSUS findings to the non-symptomatic elbows of healthy subjects.

DECLARATION OF CONFLICT OF INTEREST

This research has received funding from the Department of Science and Technology of the Republic of the Philippines. The authors declare no conflict of interest in the planning, collection, interpretation and writing of the study reported in this paper.

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REFERENCES

1. Kotnis N, Chiavaras M, Harish S. Lateral epicondylitis and beyond: imaging of lateral elbow pain with clinical radiologic correlation. *Skeletal Radiology*. 2011;41(4):369-86. [PMID: 22205505]
2. Fan JZ, Silverstein BA, Bao S, Bonauto DK, Howard NL, Spielholz PO, Smith CK, Polissar NL, Viikari-Juntura E. Quantitative Exposure-Response Relations Between Physical Workload and Prevalence of Lateral Epicondylitis in a Working Population. *American Journal of Industrial Medicine*. 2009;52:479-90. [PMID: 19347903]
3. Hamilton PG. The prevalence of humeral epicondylitis: a survey in general practice. *The Journal of the Royal College of General Practitioners*. 1986;36:464-5. [PMID: 3440991]
4. Shiri R, Varonen H, Heliovaara M, Viikari-Juntura E. Hand dominance in upper extremity musculoskeletal disorders. *The Journal of Rheumatology*. 2007;34:1076-82. [PMID: 17343320]
5. Kamien M. A rational management of tennis elbow. *Sports Med*. 1990;9:173-91. [PMID: 2180031]
6. Shiri R, Viikari-Juntura E. Lateral and medial epicondylitis: role of occupational factors. *Best practice & research. Clinical Rheumatology*. 2011;25:43-57. [PMID: 21663849]
7. Darmawan J, Valkenburg HA, Muirden KD, Wigley RD. The Prevalence of Soft Tissue Rheumatism. *Rheumatology International*. 1995;15(3):121-4.
8. Palmer K, Walker-Bone K, Linaker C, Reading I, Kellingray S, Coggon D, Cooper C. The Southampton examination schedule for the diagnosis of musculoskeletal disorders of the upper limb. *Annals of the Rheumatic Diseases*. 2000;59:5-11. [PMID: 17375604]
9. Sluiter JK, Rest KM, Frings-Dresen MH. Criteria document for evaluating the work-relatedness of upper-extremity musculoskeletal disorders. *Scandinavian Journal of Work, Environment & Health*. 2001;27 Suppl 1:1-102. [PMID: 11401243]
10. Geoffroy P, Yaffe M. Rohan I. Diagnosing and treating lateral epicondylitis. *Can Fam Physician*. 1994;40:73-8.
11. Lebrun C. What are the best diagnostic criteria for lateral epicondylitis? In: Wright, JG Evidence-based *Orthopaedics: the Best Answers to Clinical Questions*. London: Elsevier Health Sciences. 2008. p.148-57.
12. Du Toit C, Stieler M, Suanders R, Bisset L, Vicenzino B. Diagnostic accuracy of power Doppler ultrasound in patients with chronic tennis elbow. *British Journal of Sports Medicine*. 2008;42:872-6. [PMID: 18308874]
13. Quan Nha H, Marie-Jose D, Patrick L. Treatment of lateral epicondylitis: where is the evidence? *Joint Bone Spine*. 2004;71(5):369-73. [PMID: 15474386]

14. Dones VCIII, Grimmer K, Thoirs K, Suarez CG, Luker J. The diagnostic validity of musculoskeletal ultrasound in lateral epicondylalgia: a systematic review. *BMC Medical Imaging*. 2014;14(1):10. doi:10.1186/1471-2342-14-10 [PMID: 24589069]
15. Bianchi S, Martinoli C. Elbow. In Baert AL, Knauth M, Sartor K, editors. *Ultrasound of the musculoskeletal system*. Germany: Springer-Verlag Berlin Heidelberg. 2007;605-14.
16. Shahabpour M, Kichouh M, Laridon E, Gielen JL, De Mey J. The effectiveness of diagnostic imaging methods for the assessment of soft tissue and articular disorders of the shoulder and elbow. *European Journal of Radiology*. 2008; 65:194-200. [PMID: 18312783]
17. Connell D, Burke F, Coombes P, McNealy S, Freeman D, Pryde D, Hoy G. Sonographic examination of lateral epicondylitis. *American Journal of Roentgenology*. 2001;176:777-82. [PMID: 11222225]
18. Tarhan S, Unlu S, Ovali Z, Pabuscu Y. Value of ultrasonography on diagnosis and assessment of pain and grip strength in patients with Lateral Epicondylitis. *Turkish Journal of Rheumatology*. 2009;24:123-30.
19. Levin D, Nazarian LN, Miller TT, O'Kane PL, Feld RI, Parker L, McShane JM. Lateral epicondylitis of the elbow: US findings. *Radiology*. 2005;237:230-4. [PMID: 16118152]
20. Parker L, Nazarian LN, Carrino JA, Morrison WB, Grimaldi G, Frangos AJ, Levin DC, Rao VM. Musculoskeletal Imaging: Medicare use, costs, and potential for cost substitution. *Journal of the American College of Radiology*. 2008;5(3):182-8. [PMID: 18312965]
21. Lee M, Cha J, Wook J, Kim BS, Park JS, Lee HK, Hong HS. Utility of Sonographic Measurement of the Common Tensor Tendon in Patients with Lateral Epicondylitis. *AJR*. 2011;196:1363-7. [PMID: 21606300]
22. Struijs PA, Kerkhoffs GM, Assendelft WJ, Van Dijk CN. Conservative treatment of lateral epicondylitis: brace versus physical therapy or a combination of both-a randomized clinical trial. *The American Journal of Sports Medicine*. 2004;32:462-9. [PMID: 14977675]
23. Chard MD, Cawston TE, Riley GP, Gresham GA, Hazleman BL. Rotator cuff degeneration and lateral epicondylitis: a comparative histological study. *Annals of the Rheumatic Diseases*. 1994;53:30-4. [PMID: 8311552]
24. Grassi W, Filippucci E, Farina A, Cervini C. Sonographic imaging of tendons. *Arthritis and Rheumatism*. 2000;43:969-76. [PMID: 10817548]
25. Obradov M, Anderson PG. Ultrasonographic Findings for Chronic Lateral Epicondylitis. *Jbr-Btr*. 2012;95:66-70.
26. Toprak U, Baskan B, Ustuner E, Oten E, Altin L, Karademir MA, Bodur H. Common extensor tendon thickness measurements at the radiocapitellar region in diagnosis of lateral elbow tendinopathy. *Diagn Interv Radiol*. 2012; 18:566-70. [PMID: 22498913]
27. Zeisig E, Ohberg L, Alfredson H. Extensor origin vascularity related to pain in patients with Tennis elbow. *Knee Surg Sports Traumatol Arthrosc*. 2006;14:659-63. [PMID: 16555106]
28. Cyriax JH. The pathology and treatment of tennis elbow. *Journal of Bone and Joint Surgery*. 1936;18:921.
29. Thurston AJ. The early history of tennis elbow: 1873 to the 1950s. *The Australian and New Zealand Journal of Surgery*. 1998;68:219-24. [PMID: 9563455]
30. Kraushaar B, Nirschl R. Current Concepts Review – Tendinosis of the Elbow (Tennis Elbow). Clinical Features and Findings of Histological, Immunohistochemical and Electron Microscopy Studies. *The Journal of Bone and Joint Surgery*. 1999;81:259-78. [PMID: 10073590]
31. Oken O, Kahraman Y, Ayhan F, Canpolat S, Rezan Yorgancioglu Z, Fuad Oken O. The short-term efficacy of laser, brace, and ultrasound treatment in lateral epicondylitis: a prospective, randomized, controlled trial. *Journal of Hand Therapy: Official Journal of the American Society of Hand Therapist*. 2008;21:63-7. [PMID: 18215753]
32. Wuori JL, Overend TJ, Kramer JF. Macdermid J. Strength and pain measures associated with lateral epicondylitis bracing. *Archives of Physical Medicine and Rehabilitation*. 1998;79:832-7. [PMID: 9685101]
33. D'Vaz AP, Ostor AJ, Speed CA, Jenner JR, Bradley M, Prevost AT, Hazleman BL. Pulsed low-intensity ultrasound therapy for chronic lateral epicondylitis: a randomized controlled trial. *Rheumatology*. 2006;45:566-70. [PMID: 16303817]
34. Radpasand M, Owens E. Combined multimodal therapies for chronic tennis elbow: pilot study to test protocols for a randomized clinical trial. *Journal of Manipulative and Physiological Therapeutics*. 2009;32:571-85. [PMID: 19748409]
35. Basford JR, Sheffield CG, Cieslak KR. Laser therapy: a randomized, controlled trial of the effects of low intensity Nd:YAG laser irradiation on lateral epicondylitis. *Archives of Physical Medicine and Rehabilitation*. 2000;81:1504-10. [PMID: 11083356]
36. Martinez-Silvestrini JA, Newcomer KL, Gay RE, Schaefer MP, Kortebein P, Arendt KW. Chronic lateral epicondylitis: comparative effectiveness of a home exercise program including stretching alone versus stretching supplemented with eccentric or concentric strengthening. *Journal of Hand Therapy: Official Journal of the American Society of Hand Therapists*. 2005;18:411-9. [PMID: 16271688]
37. Rompe JD, Decking J, Schoellner C, Theis C. Repetitive low-energy shock wave treatment for chronic lateral epicondylitis in tennis players. *The American Journal of Sports Medicine*. 2004;32:734-43. [PMID: 15090392]

38. Archambault JM, Hart D, Herzog W. Response of rabbit Achilles tendon to chronic repetitive loading. *Connective Tissue Research*. 2001;42:13-23. [PMID: 11696985]
39. Soslowsky LJ, Thomopoulos MS, Tun S, Flanagan CL, Keefer CC, Maslaw BSJ, Carpenter JE. Neer Award 1999. Overuse activity injures the supraspinatus tendon in an animal model: a histologic and biomechanical study. *Journal of Shoulder and Elbow Surgery*. 2000;9:79-84. [PMID: 10810684]
40. Dones VCIII, Grimmer-Somers K, Thoirs K, Gonzalez-Suarez C. Inter-tester reliability of sonographers in detecting pathological lesions in the elbow of individuals with Lateral Epicondylar pain. *Journal of Musculoskeletal Research*. 2011;14:1-14.
41. De Zordo T, Lill SR, Fink C, Feuchtner GM, Jaschke W, Bellmann-Weiler R, Klauser AS. Real-Time Sonoelastography of Lateral Epicondylitis: comparison of findings between patients and healthy volunteers. *American Journal of Roentgenology*. 2009;193:180-5. [PMID: 19542412]
42. MEDCALC for Windows statistics for biomedical research software manual, version 11.3, MedCalc easy-to-use statistical software, 2012-2013. [cited 22 February 2013]. Available from: http://www.medcalc.org/manual/index.php
43. Stanish WD, Curwin S, Rubinovich M. Tendinitis: the analysis and treatment for running. *Clinics in Sports Medicine*. 1985;4:593-609. [PMID: 3902252]
44. Chen JH, Liu C, You L, Simmons CA. Boning up on Wolff's Law: Mechanical regulation of the cells that make and maintain bone. *J Biomech*. 2010;43(1):108-18. [PMID: 19818443]
45. Struijs P, Spruyt M, Assendelft W, van Dijk CN. The Predictive Value of Diagnostic Sonography for the Effectiveness of Conservative Treatment of Tennis Elbow. *AJR*. 2005;185:1113-8. [PMID: 16247118]
46. Croisier JL, Foidart-Dessalle M, Tinant F, Crielaard JM, Forthomme B. An isokinetic eccentric programme for the management of chronic lateral epicondylar tendinopathy. *British Journal of Sports Medicine*. 2007;41:269-75. [PMID: 17224433]
47. Martinez-Silvestrini JA, Necomer KL, Gay RE, Schaefer MP, Kortebein P, Arendt KW. Chronic lateral epicondylitis: comparative effectiveness of a home exercise program including stretching alone versus stretching supplemented with eccentric or concentric strengthening. *Journal of Hand Therapy*. 2005;18:411-9. [PMID: 16271688]
48. Bisset L, Paungmali A., Vicenzino B., Beller E. A systematic review and meta-analysis of clinical trials on physical interventions for lateral epicondylalgia. *British Journal of Sports Medicine*. 2005;39:411-22. [PMID: 15976161]
49. Clements LG, Chow S. Effectiveness of a custom-made below elbow lateral counterforce splint in the treatment of lateral epicondylitis (tennis elbow). *Canadian Journal of Occupational Therapy*. 1993;60:137-44.
50. Gerdesmeyer L, Wagenpfeil S, Haake M, Maier M, Loew M, Wortler K, Lampe R, Seil R, Handle G, Gassel S, Rompe J. Extracorporeal shock wave therapy for the treatment of chronic calcifying tendonitis of the rotator cuff: a randomized controlled trial. *Journal of the American Medical Associations*. 2003;290:2573-80. [PMID: 14625334]
51. Grimmer-Somers K, Lekkas P, Jeffries L, Kumar S, O'Dywer L, Massey-Westropp N, Legg S, Olsen K. *Distal upper limb: guidelines for management of some musculoskeletal disorders*. ACC Report on ACC Website (www.acc.co.nz/publication/index), Comprehensive Version, 30 July 2009
52. Hatch GF3rd, Pink MM, Mohr KJ, Sethi PM, Jobe FW. The effect of tennis racket grip size on forearm muscle firing patterns. *The American Journal of Sports Medicine*. 2006;34:1977-83. [PMID: 16861576]
53. Nirschl RP. Prevention and treatment of elbow and shoulder injuries in the tennis player. *Clinics in Sports Medicine*. 1988;7:289-308. [PMID: 3292065]
54. Wuori JL, Overend TJ, Kramer JF, Macdermid J. Strength and pain measures associated with lateral epicondylitis bracing. *Archives of Physical Medicine and Rehabilitation*. 1998;79:832-7. [PMID: 9685101]
55. Menz HB. Two feet, or one person? Problems associated with statistical analysis of paired data in foot and ankle medicine. *The Foot*. 2004;14:2-5.
56. Zeisig E, Fahlstrom M, Ohberg L, Alfredson H. A two-year sonographic follow-up after intratendinous injection therapy in patients with tennis elbow. *Br J Sports Med*. 2010;44:584-7. [PMID: 18664498]
57. Noh KH, Moon YL, Jacir AM, Kim KH, Gorthi V. Sonographic probe induced tenderness for lateral epicondylitis: an accurate technique to confirm the location of the lesion. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*. 2010;18:836-9. [PMID: 20111954]
58. Khoury V, Cardinal E. "Tenomalacia": a new sonographic sign of tendinopathy? *European Radiology*. 2009; 19:144-6. [PMID: 18677489]
59. Miller TT, Shapiro MA, Schultz E, Kalish PE. Comparison of sonography and MRI for diagnosing epicondylitis. *Journal of Clinical Ultrasound: JCU*. 2002;30:193-202. [PMID: 11981928]
60. Maffulli N, Regine R, Carrillo F, Capasso G, Minelli S. Tennis elbow: an ultrasonographic study in tennis players. *British Journal of Sports Medicine*. 1990;24:151-5. [PMID: 2078798]

APPPENDIX A
Sensitivity and Specificity of MSUS Findings in Elbows with LE

	Obradov et al. (2012)[25]		Toprak et al. (2012)[26]		Lee et al. (2011)[21]		Zeisig et al. (2010)[56]	Noh et al. (2010)[57]		Du Toit et al. (2008)[12]		Struijs et al. (2005)[45]	
N=px,elbows	43,49		164,248		48,51		25,28	27,27		25,32		57,57	
Age (in years)	Mean(SD):47(7.7)		Mean: 43 Range: 19-66		Mean: 48.3 Range: 34-66		Mean:46 Range: 27-66	Median:44 Range:37-59		Mean: 50 SD: 9		Mean: 45.5 SD: 12.8	
Duration of symptoms	At least 6 mos		Generally chronic		Mean: 3 mos. Range: 2 wks-6 mos		Mean: 18 mos Range: 3-60 mos	Mean:8.7 wks Range: 3-18 wks		Min-max: 3-120 mos.		Mean (SD): 17(11.3) wks	
	SnS(%)	SpC(%)	SnS(%)	SpC(%)	SnS(%)	SpC(%)	SnS(%)	SnS(%)	SpC(%)	SnS(%)	SpC(%)	SnS(%)	SpC(%)
Hypoechogenicity	86 (73-94)	100 (69-100)	--	--	35 (22-50)	94 (85-98)	--	59 (39-78)	85 (66-96)	--	--	67 (53-79)	81 (68-90)
Neovascularity	57 (42-71)	--	19 (14-24)	100 (98-100)	--	--	100 (88-100)	--	--	81 (64-93)	98 (90-100)	--	--
Calcifications	71 (58-82)	90 (59-98)	31 (25-37)	99 (96-100)	6 (1-16)	95 (87-99)	--	--	--	--	--	5 (1-15)	100 (94-100)
Margin	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent fluid	--	--	--	--	4 (1-13)	100 (94-100)	--	--	--	--	--	--	--
Fibrillar pattern	--	--	--	--	--	--	--	--	--	--	--	--	--
Thickness	--	--	52 (46-58)	47 (34-60)	86 (74-94)	83 (71-91)	--	--	--	72 (47-90)	53 (29-76)	61	84
Tear	35 (29-41)	100 (98-100)	35(29-41)	100 (98-100)	--	--	--	--	--	--	--	--	--
Cortical irregularities	18 (9-32)	100 (69-100)	55 (48-61)	91 (86-95)	18 (8-31)	95 (87-99)	8 (3-17)	--	--	63 (44-79)	63 (49-75)	--	--
Enthesopathy	--	--	--	--				56 (35-75)	85 (66-96)	--	--	65 (51-77)	86 (74-94)

Key: LE, lateral epicondylalgia; mo(s), month(s); MSUS, musculoskeletal ultrasound; n, number; px, participants; Sns, sensitivity; Spc, specificity; wk(s), week(s); --, not reported

Continuation on Sensitivity and Specificity of MSUS Findings in Elbows with LE

	De Zordo et al. (2009)[41]		Khoury and Cardinal (2009)[58]	Tarhan et al. (2009)[18]	Zeisig et al. (2006)[27]		Miller et al. (2002)[59]		Connell et al. (2001)[17]	Maffulli et al. (1990)[60]	
N=px,elbows	32,38		8,8	52,52	17,22		8,8		76,72	41,41	
Age (in years)	Mean: 52.6 Range: 38-70		Mean:45	Mean(SD): group 1: 49.8(9.6) Group 2: 44.8(8.9)	Mean: 45		Mean: 46 Range: 38-63		Mean: 45.6 Range: 21-67	Mean(SD): 24.3,7.3 Range: 16-36	
Duration of symptoms	Mean: 9 mos Range: 6-120 mos		Not indicated	Mean: 8.2 Range: 1-72 mos	Mean: 18 mos		Mean: 7.6 mos. Range: 3 wks-2 yrs.		Mean: 7.1 mos. Range: 1 day-9 yrs	Mean: 2.2 mos. Range: 17 days to 9.8 mos	
	SnC(%)	SpC(%)	SnS(%)	SnS(%)	SnS(%)	SpC(%)	SnS(%)	SpC(%)	SnS(%)	SnS(%)	SpC(%)
Hypoechogenicity	89 (75-97)	89 (75-96)	100 (63-100)	--	100 (85-100)	0	63 (24-91)	100 (54-100)	64 (52-75)	--	--
Neovascularity	--	--	100 (63-100)	--	95 (77-100)	91 (71-99)	--	--	0 (0-5)	--	--
Calcifications	--	--	13 (0-53)	10 (3-21)	50 (19-81)	100 (85-100)	--	--	11 (5-21)	--	--
Margin	--	--	--	--	--	--	--	--	--	--	--
Adjacent fluid	--	--	--	--	--	--	--	--	--	--	--
Fibrillar pattern	--	--	--	--	--	--	--	--	--	--	--
Thickness	--	--	100 (63-100)	--	--	--	64 (24-91)	100 (54-100)	35 (24-47)	12 (4-26)	0
Tear	--	--	--	10 (3-21)	--	--	--	--	25 (16-37)	--	--
Cortical irregularities	--	--	--	--	--	--	--	--	22 (13-34)	--	--
Enthesopathy			63 (24-91)	8 (2-19)	--	--	--	--	--	12 (4-26)	0

Key: LE, lateral epicondylalgia; mo(s), month(s); MSUS, musculoskeletal ultrasound; N, number; px, participants; Sns, sensitivity; Spc, specificity; wk(s), week(s); --, not reported

In an attempt to understand better the pathology in elbows with LE, improvements and increased use of musculoskeletal ultrasound (MSUS) have proliferated since 2001.[38] In evaluating LE, MSUS has objectively detected pathology within the CEO and around the lateral epicondyle (Tarhan et al., 2009, du Toit et al., 2008, Levin et al., 2005).[31,35,40]

APPENDIX B

Diagnostic Validity Expressed as Percentages (95% Confidence Intervals) for Musculoskeletal Findings in the Elbows of Participants with LE

	Acute (current LE symptoms of < 6 weeks							Chronic (current LE symptoms of > 6 weeks						
	Sns	*Spc*	*PPV*	*NPV*	*PLR*	*NLR*	*DOR*	*Sns*	*Spc*	*PPV*	*NPV*	*PLR*	*NLR*	*DOR*
Common Extensor Tendon														
Hypoechogenicity	67 (46-82)	38 (21-60)	55 (38-72)	50 (28-72)	1.08 (0.70-1.67)	0.88 (0.40-1.92)	1.52 (0.43-5.38)	81 (64-91)	64 (45-80)	74 (57-85)	73 (52-87)	2.2 (1.30-3.88)	0.30* (0.14-0.66)	7.41** (2.21-24.81)
Neovascularity	8 (2-26)	95 (77-100)	67 (21-94)	48 (33-62)	1.75 (0.17-17.10)	0.96 (0.83-1.12)	1.81 (0.15-21.60)	16 (7-33)	92 (75-98)	71 (36-92)	47 (34-61)	2.02 (0.43-9.53)	0.91 (0.75-1.11)	5.76 (0.65-51.46)
Calcifications	42 (24-61)	90 (71-97)	83 (55-95)	58 (41-73)	4.38* (1.08-17.75)	0.65 (0.45-0.93)	14.62** (1.66-128.43)	39 (24-56)	92 (75-98)	86 (60-96)	55 (40-69)	4.84* (1.19-19.65)	0.67 (0.50-0.90)	7.26** (1.44-36.54)
Margins	4 (1-20)	100 (85-100)	100 (21-100)	48 (34-62)	—	0.96 (0.88-1.04)	2.73 (0.11-70.93)	6 (2-21)	100 (87-100)	100 (34-100)	46 (34-60)	—	0.94 (0.85-1.03)	4.32 (0.20-94.26)
Adjacent fluid	4 (1-20)	100 (85-100)	100 (21-100)	48 (34-62)	—	0.96 (0.88-1.04)	2.73 (0.11-70.93)	0 (0-11)	96 (80-100)	0 (0-80)	44 (31-57)	0	1.04 (0.96-1.13)	0.26 (0.01-6.65)
Fibrillar pattern	8 (2-26)	95 (77-99)	67 (21-94)	48 (34-62)	1.75 (0.17-17.95)	0.96 (0.83-1.12)	1.81 (0.15-21.60)	6 (2-21)	92 (75-98)	50 (15-85)	44 (32-58)	0.81 (0.12-5.33)	1.02 (0.88-1.18)	2.57 (0.25-26.38)
Thickness	13 (4-31)	100 (85-100)	100 (44-100)	50 (36-64)	—	0.88 (0.75-1.02)	7.00 (0.34-144.28)	13 (5-29)	96 (80-100)	80 (38-96)	47 (34-61)	3.27* (0.38-27.06)	0.91 (0.78-1.06)	3.56 (0.37-34.05)
Tear	4 (1-20)	100 (85-100)	100 (21-100)	48 (34-62)	—	0.96 (0.88-1.04)	2.73 (0.11-70.93)	3 (1-16)	100 (87-100)	100 (21-100)	45 (33-58)	—	0.97 (0.91-1.03)	2.51 (0.10-64.27)
Lateral Epicondyle														
Cortical irregularities	30 (15-50)	81 (60-92)	64 (35-85)	50 (34-66)	1.53 (0.52-4.51)	0.88 (0.63-1.22)	3.94 (0.71-21.76)	23 (11-40)	76 (57-89)	54 (29-77)	44 (30-49)	0.94 (0.36-2.44)	1.02 (0.76-1.36)	1.39 (0.39-4.94)

**Generate small but sometimes important shifts in probability*

***p<0.05*

Key: DOR, diagnostic odds ratio; LE, Lateral Epicondylalgia; NLR, negative likelihood ratio; NPV, negative predictive value; PLR, positive likelihood ratio; PPV, positive predictive value; Spc, specificity; Sns, sensitivity; __infinity