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Ultrasound with shear wave elastography in diagnosis and follow-up of common extensor tendinopathy in cases with lateral epicondylitis: a cross-sectional analytic study

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Abstract

Background: Lateral epicondylitis (LE) is a common non-traumatic condition. The diagnosis of LE is typically made clinically. Some lateral epicondylitis patients can profit from supplementary imaging for a precise differential diagnosis. Recently, shear wave elastography has been increasingly attracting public attention in evaluation of tendon pathology and tissue elasticity quantitatively. The purpose of our study was to prove that shear wave elastography can be utilized in the diagnosis and follow-up of lateral epicondylitis.

Results: This cross-sectional analytic study involved 42 patients with unilateral lateral epicondylitis (30 males, 12 females with age range: 30–50 years, mean age: 39.9 ± 6 SD). The patients were reviewed by two radiologists with experience of more than 10 years, blinded to each other's results. Lateral epicnodylitis was diagnosed based on clinical criteria. The thickness of common extensor tendon and shear wave speed (SWS) were acquired in elbows bilaterally, along with values of the involved elbows in pre- and post-treatment phases. The comparison between examined groups, inter-rater and intra-rater concordance, and the diagnostic performance have been investigated with paired *t*-test, an intraclass correlation coefficients (ICCs), and a receiver operator characteristic curve, respectively. The patients with lateral epicondylitis showed a significantly decreased value of shear wave speed on affected side in comparison to the healthy side (*P* value: 0.000). The shear wave speed of diseased elbows has increased significantly following non-operative management than before therapy. The inter-rater and intra-rater concordance showed both excellent values (ICCs ranged from 0.939 to 1.000) for shear wave speed measurements. Furthermore, a 10.72 m/s cut-off limit of mean SWS (shear wave speed) for differentiating lateral epicondylitis elbows from healthy elbows showed a sensitivity and specificity of 90.5% for both.

Conclusions: Shear wave elastography can be of value as a technique with proper reproducibility and proper diagnostic performance for evaluation and monitoring the therapeutic effect in patients with lateral epicondylitis.

Keywords: The common extensor tendon, Lateral epicondylitis patients, The shear wave elastography, Shear wave speed

Background

Lateral epicondylitis, also recognized as tennis elbow, is a non-traumatic condition. It is the second most common pathology of the diseases of the upper limbs. It is considered as a common extensor tendinopathy related to the tendon insertion at the lateral epicondyle [1].

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The reference for establishing a diagnosis of lateral epicondylitis depends mainly on a relevant history and physical examination. The chief complaint of the patients is pain and local tenderness overlying the lateral aspect of elbow that is aggravated by wrist extension and digital resisting [2].

In this setting, ultrasound or magnetic resonance imaging can be implemented to offer data regarding the differential diagnosis and extent of the disease. Although MRI has a higher sensitivity in the accurate evaluation of CET with an excellent contrast resolution of soft tissue, ultrasound may be more efficient in daily practice, considering that ultrasound is an examination of low cost, it provides images quickly and it has a high ability to examine superficial soft tissue structures [3–6].

Recently, ultrasound (US) has achieved more and more importance in the evaluation of tendinopathies. Ultrasound has the benefits of being dependable, noninvasive, highly available and provides a rapid support to clinical examination with no diagnostic delay [7–11].

In literature, previously reported sensitivity and specificity values of gray-scale ultrasound in diagnosing tennis elbow show a wide variability and range from 72 to 88%, and from 36 to 100%, respectively. The widely variable data in published research regarding the sensitivity and specificity of gray-scale ultrasound have been ascribed to a significant rate of false positive gray-scale ultrasound results [12].

Elastography in ultrasound was established to assess the extent of distortion of tissue in response to an applied internal or external force. Multiple elastography ultrasound techniques were applied for the application of stress to tissue. The main two methods evaluated are strain elastography and shear wave elastography (SWE). Notably, strain elastography shows a high operator dependency. On the other hand, shear wave elastography is a distinctive technique centered on acoustic radiation force impulse (ARFI), where tissue compression is applied using an acoustic push beam, with comparison of tissue stiffness to surrounding structures without depending on tissue compression by the operator [13].

Additionally, shear wave elastography (SWE) is a rather new ultrasound technique, a helpful tool to gray-scale ultrasound, that gives values (i.e., Young's modulus (kilopascals)) and shear wave speed (m/s) that are closely related to the functional viscoelastic criteria of tendons. Previously, literature has shown the ability of shear waves to propagate through tendons according to probe position and extent of tendon inflammation, showing higher speed in healthy tendons compared to diseased ones [14].

Nevertheless, shear wave elastography examination of the common extensor tendon in lateral epicondylitis patients has infrequently been studied, and most studies only assessed the common extensor tendon with strain elastography [15–18].

Thus, the aim of our study was to assess the feasibility of shear wave elastography as a diagnostic modality for lateral epicondylitis. The present study evaluated common extensor tendon elasticity in patients with unilateral lateral epicondylitis by quantitative shear wave elastography and observed the disease condition before and after the non-operative treatment.

Methods

Approval of the ethics committee was obtained for this cross-sectional analytic study. We reviewed 42 patients (30 males, 12 females with age range: 30–50 years, mean age: 39.9 ± 6 SD), with a clinical diagnosis of unilateral lateral epicondylitis after being evaluated by an orthopedic surgeon. Demographic information including sex, age, the dominant hand, involved hand and duration of the disease are shown in Table 1. The patients were recruited from orthopedic department of our institution from January 2022 to July 2022. The involved patients had a characteristic history, with tenderness over the lateral humeral epicondyle, and pain provoked by extension and twist that was referred from the lateral forearm to the palm of the hand. The elbows of all patients were evaluated bilaterally using shear wave elastography earlier than and following non-operative management. All of examined patients were subjected to non-operative (physical)

Table 1 The baseline demographic data of the patients

Characteristic	Description ($n = 42$)
Age (years)	
Range	30–50
Mean ± SD	39.9 ± 6
Sex	
Male	30(71.4%)
Female	12(28.6%)
Dominant side	
Right	36 (85.7%)
Left	6 (14.3%)
Involved side	
Right	34 (81%)
Left	8 (19%)
Involved side	
Dominant	40 (95.2%)
Non-dominant	2 (4.8%)
Disease duration (range) in days	
Range	1–166
Mean ± SD	82.3 ± 49.4

treatment for a duration of one month following the first ultrasound examination. Patients have been excluded in cases where they had a history of lateral epicondylitis on both sides, history of fracture of elbows, surgery of elbows. They were also excluded in case they were diagnosed with systemic diseases of musculoskeletal system, or were pregnant.

The shear wave elastography and the tendon thickness assessments were performed using a Toshiba Aplio 500 ultrasound system (Toshiba Medical Systems Corporation, Tokyo, Japan) using a linear transducer (12 MHz). The patients were asked to sit facing the radiologist performing the examination with the elbow in a flexed position at 90° and with the thumb pointing upward, with the forearm being in a relaxed position all through the examination**.** The transducer should be applied in a position perpendicular to the lateral epicondyle with minimal contact with the utilization of a coupling agent to reduce the effect of pressure applied. A longitudinal scan of common extensor tendon attached to the humeral lateral epicondyle was acquired to obtain the images of B mode, and the elastograms appeared as an overlay in dual-mode beside the B-mode image. The thickness of common extensor tendon was evaluated as the distance lying between the extensor tendon surface and the humeral cortex at the level of the capitulum (Fig. 1). The represented color code denoted the tissue elastic properties inside the region of interest (ROI) with colors varying from blue to red, signifying soft to hard consistency, respectively. Afterward, the combined shear wave elastograms mechanically revealed shear wave speed (SWS) and Young's modulus, and shear wave speed was the main value utilized for our study. The examiner adjusted the examination setting to a superficial musculoskeletal configuration. The displayed size of the region of interest (ROI) was the same in all examined cases. Because of the potential drawbacks of shear wave elastography regarding adjacency to the bones, caution was followed not to put the circular region of interest (ROI) out of the borders of the common extensor tendon (CET) and adjacent to bone. Figure 2 illustrates the standard shear wave elastography (SWE) image.

The thickness and elastographic measurements were evaluated by two musculoskeletal radiologists (operator 1 and operator 2), each with more than 10 years of experience, blinded to the results of each other. Each operator independently assessed all 42 subjects in order to assess for the inter-rater agreement. During the first week after the ultrasound examination, the same 42 patients were reexamined by operator 1 to evaluate the intra-rater agreement. After non-operative physical treatment, operator 1 conducted CET thickness measurement and ultrasound elastography of all patients again as previously described. CET stiffness values were measured three times by each observer. The values were obtained from the same area of the tendon at the capitellar region, and the mean, minimum, and maximum shear wave speeds (SWS) calculated in meters per second (m/s) for every tendon have been utilized for the study, added to the mean thickness.

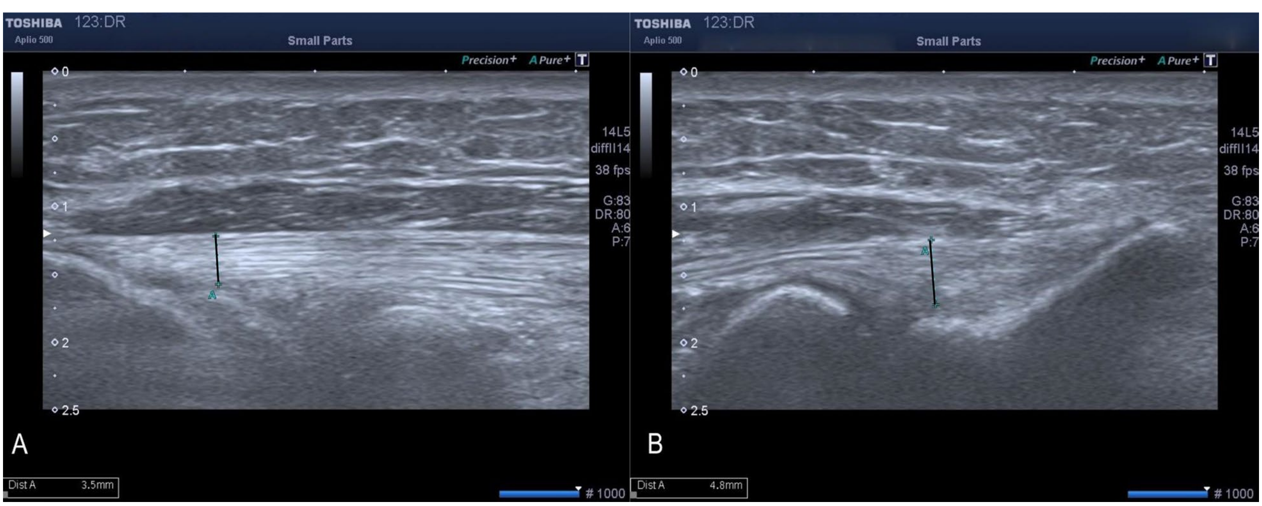

Fig. 1 Ultrasound images of the bilateral common extensor tendon (CET) on longitudinal axis in a 50-year-old female patient with unilateral lateral epinodylitis presenting with unilateral pain along the lateral aspect of the forearm and elbow. **A** Thickness of the healthy CET was measured at the capitellar region. The CET measured 3.5 mm in thickness. **B** Thickness of involved contralateral CET at the capitellar region. The CET measured 4.8 mm in thickness

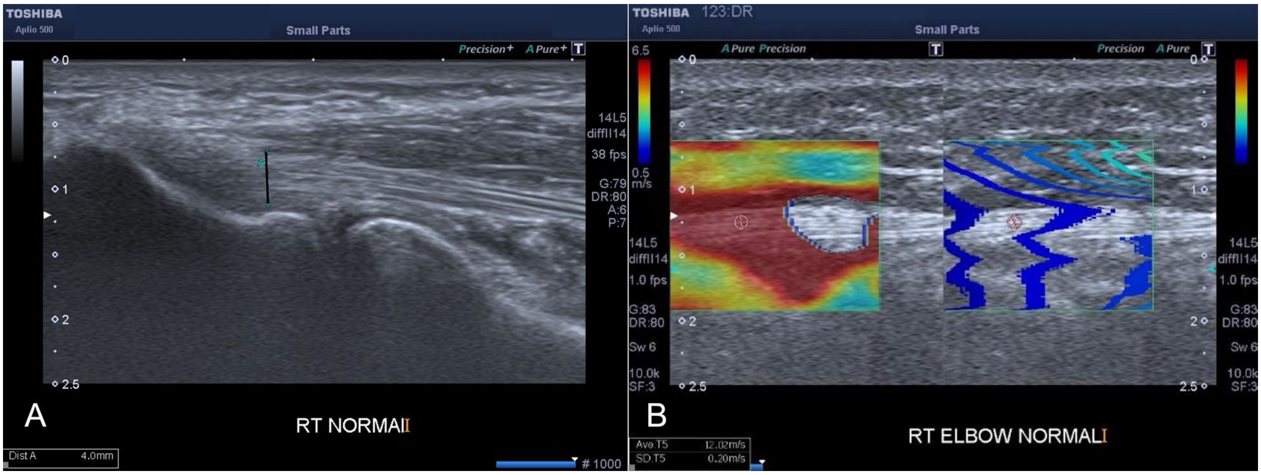

Fig. 2 Ultrasound images of a healthy common extensor tendon (CET) of a 32-year-old male patient. **A** Gray-scale longitudinal scan of the patient showing normal CET thickness. **B** Shear wave elastograpm (SWE) of the same patient.The left sided image is a longitudinal gray-scale ultrasound (US) examination of CET with superadded color box borders for the SWE map. There is a circular ROI for quantitative measurement of SWS on the right sided image. Shear wave speed (SWS) of the CET was measured to be 12.02 m/s at the capitellar region

Statistical analysis

Data were entered and statistically analyzed on the Statistical Package of Social Science Software program, version 25 (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.). Data were presented using mean and standard deviation for quantitative variables and frequency and percentage for qualitative ones. Comparison between groups for qualitative variables was performed using Chi-square or Fisher's exact tests while for quantitative variables the comparison was conducted using the independent sample *t*-test. Pearson correlation coefficients were calculated to assess the correlation between different quantitative variables. The validity of different measures was assessed using Receiver Operating Characteristics (ROC) analysis. Inter-rater and intra-rater concordance of different measures was assessed using Intra-class correlation coefficients (ICC). The ICCs between 0.75 and 0.9, and those greater than 0.90 were indicative of good and excellent reliability, respectively. P values less than or equal to 0.05 were considered statistically significant.

The standard of reference

A clinical diagnosis of lateral epicondylitis was considered the gold standard technique.

Results

A total of 42 patients with unilateral lateral epicondylitis were involved. The mean shear wave speed (SWS) pretherapy was not associated with age, gender or disease duration ($P=0.680$, 0.573 and 0.544, respectively). Notably, a very high correlation was noted between the dominant hand and the involved elbow with a P value of 0.000.

The thickness of common extensor tendon in unilateral lateral epicondylitis cases showed a significant higher measurement in diseased common extensor tendon (CET) (5.2 ± 0.3 mm) compared to the non diseased common extensor tendon (3.9 ± 0.2 mm) (P value: 0.000). A cut off value of ≥ 4.85 mm showed a sensitivity and specificity of 90.5% and 85.7%, respectively, with an AUC of 0.941. No correlation was found between tendon thickness, age, sex or disease duration. Moreover, a statistically significant difference was noted regarding the common extensor tendon thickness among measurements prior to and after non-operative treatment (*P* value: 0.000). Notably this thickness value was significantly reduced after non-operative treatment (4.6 ± 0.4 mm). The elastograms of healthy elbows showed a stiff common extensor tendon mostly corresponding to red colored regions, while the blue and green colored regions were noted in elbows with lateral epicondylitis indicating a decreased stiffness. Also, comparison between both sides in terms of shear wave velocities revealed a significant difference between the elbows with lateral epicondylitis and the healthy control elbows (Fig. 3). Notably, the three measured velocities of the lateral epicondylitis elbows were significantly reduced compared to the healthy side (P value: 0.000). Moreover, the shear wave speed detected concerning the elbows affected with lateral epicondylitis revealed higher values of significant nature in post-treatment measurements compared to the pre-treatment measurements (*P* value: 0.000) (Table 2 and Fig. 4).

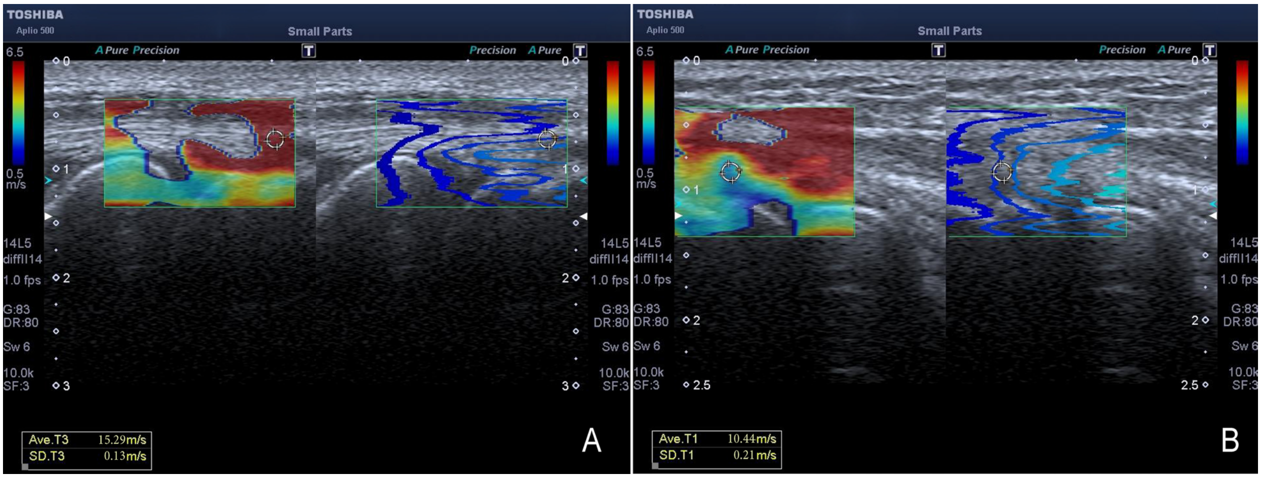

Fig. 3 Shear wave elastography (SWE) ultrasound of bilateral common extensor tendon (CET) on longitudinal scan in a 46-year-old male patient presenting with unilateral pain along the lateral aspect of the forearm and elbow. **A** SWE of the healthy CET showing mostly red regions, denoting the stiff nature of tendon structure. Quantitative SWE measurement shows the shear wave speed (SWS) to be 15.29 m/s. **B** SWE of involved CET showing mostly blue areas, denoting the soft nature of tendon structure. Quantitative SWE measurement shows the shear wave speed (SWS) to be 10.44 m/s

Table 2 The thickness and shear wave speed (SWS) values of bilateral elbows in patients with unilateral lateral epicondylitis (LE)

SWS (m/s)	Bilateral elbows		*P* value	LE elbows		*P* value
	LE elbows	Healthy elbows		Pre-therapy	Post-therapy	
Thickness	5.2 ± 0.3	3.9 ± 0.2	**0.000**	5.2 ± 0.3	4.6 ± 0.4	**0.000**
Mean SWS	9.5 ± 0.8	13.5 ± 0.7	**0.000**	9.5 ± 0.8	11.6 ± 1	**0.000**
Minimum SWS	8.4 ± 0.7	11.2 ± 0.7	**0.000**	8.4 ± 0.7	9.4 ± 1.1	**0.000**
Maximum SWS	11.3 ± 0.9	15.3 ± 0.5	**0.000**	11.3 ± 0.9	13.9 ± 0.8	**0.000**

Bold indicates statistically significant values

The values of involved elbows in pre- and post-therapy stages are also demonstrated

Data are mean ± standard deviation

SWS shear wave speed, *m/s* meter per second, *LE* lateral epicondylitis

The results of inter- and intra-rater agreement of common extensor tendon thickness and SWE measurements in the examined 42 patients are shown in Table 3. Apart from the interobserver reliability of common extensor tendon thickness which showed a good agreement with an ICC value of 0.880, all other ICC values showed excellent inter- and intra-rater agreements, as ICC values ranged from 0.939 to 1.000.

The ROC curves for the evaluation of lateral epicondylitis established based on the common extensor tendon thickness and shear wave speed are shown in Fig. 5, in which the mean SWS presents the highest diagnostic accuracy with the highest area under the curve seen measuring 0.973 (95% CI: 0.947–1.000). After the mean shear wave speed (SWS) was used for establishing the diagnosis of lateral epicondylitis (LE) with a mean cut off value of 10.72 m/s, both the sensitivity (90.5%) and specificity (90.5%) were high (Table 4).

Discussion

Lateral epicondylitis, is a disease of the common extensor tendon [2]. Currently, there is need for other imaging modalities to overcome limitations of MRI and ultrasound which can be fulfilled by elastography [18]. Elastography evaluates tissue biomechanical and structural properties [19, 20]. Shear wave elastography allows quantitative assessment of tissue elasticity [21]. Shear waves show higher speed in denser tissue which can be helpful for diagnosis and assessment of diseases affecting tissue stiffness. Consequently, assessment of tendon softening by ultrasound elastography may be of added value for diagnosis of patients with lateral epicondylitis [21, 22].

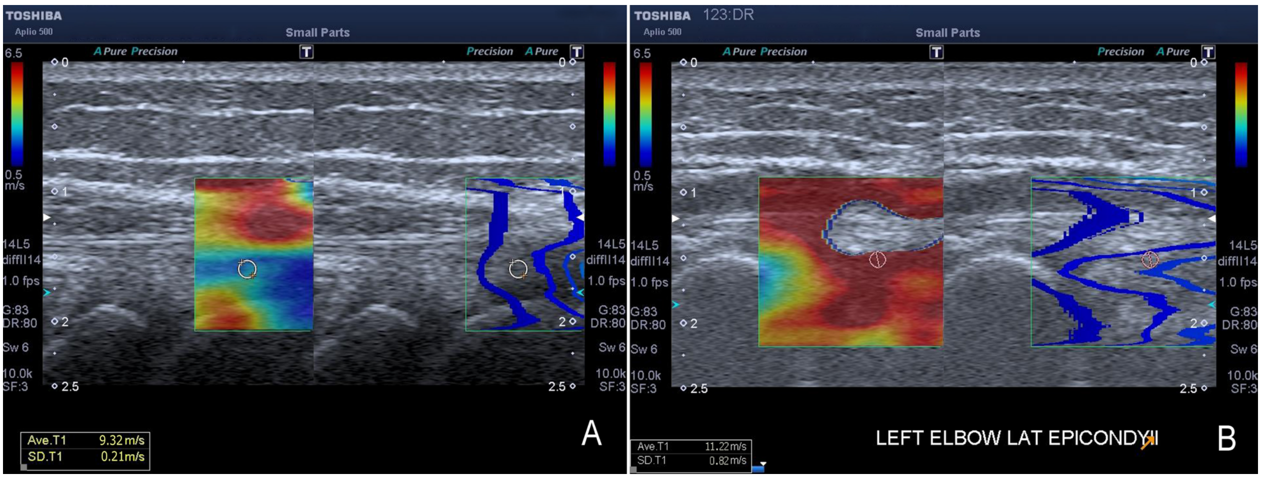

Fig. 4 Shear wave elastography (SWE) ultrasound of the same common extensor tendon (CET) with lateral epicondylitis on longitudinal scan **A** before non-operative management when the patient was complaining of pain along lateral aspect of elbow joint and **B** after non-operative management with reduced intensity of pain in a 52-year-old male patient. The change in shear wave speed (SWS) proved that SWE could monitor the treatment effect

Table 3 ICCs for inter- and intra-observer concordance for thickness and shear wave speed (SWS) measurements

	LE elbows				
	SWS (m/s)			ICCs	
	Operator 1	Operator 2	Operator 1′	Inter-observer	Intra-observer
Thickness	5.2 ± 0.3	5.2 ± 0.4	5.2 ± 0.3	0.880 (0.787–0.934)	0.999 (0.999–1.000)
Mean SWS	9.5 ± 0.8	9.6 ± 0.7	9.6 ± 0.8	0.974 (0.953–0.986)	0.998 (0.995–0.999)
Minimum SWS	8.4 ± 0.7	8.4 ± 0.7	8.4 ± 0.7	0.939 (0.890–0.967)	0.999 (0.995–1.000)
Maximum SWS	11.3 ± 0.9	11.3 ± 1	11.3 ± 0.9	0.964 (0.934–0.980)	1.000 (0.973–1.000)

Data are means ± standard deviation.SWS, shear wave speed; m/s, meter per second; Operator 1′, operator 1 thickness and shear wave speed values after one week, ICCs, intraclass correlation coefficients

Toprak et al. [23] demonstrated higher sensitivity and specificity when combining the common extensor tendon thickness values at capitellar and humero-radial joint regions for diagnosing lateral epicondylitis. Toprak et al. also found CET thickness at humero-radial joint to be 3.24 mm in non dominant and 3.53 mm in dominant sides in the control group. Sendur et al. results [16] also demonstrated a mean thickness of 3.5 mm at the humeroradial level. Hence, both Toprack and Sendur et al. [16, 23] measurements of a healthy common extensor tendon thickness were compatible to our results. A study by Lee et al. [24] showed CET thickness value cutoff level of 4.2 mm to highly increase sensitivity, specificity, and accuracy in diagnosing lateral epicondylitis. Common extensor tendon thickness was evaluated over the capitellar region, which was similar to our results. On the other hand, the study by Krogh et al. [1] demonstrated inefficiency and inapplicability of CET thickness assessment as a diagnostic modality for lateral epicondylitis, stating that it may complement clinical diagnosis but cannot rule out lateral epicondylitis on its own.

Our study has revealed that the CET has a softer elasticity in elbows with lateral epicondylitis when measured with SWE. Multiple causes of lateral epicondylitis have been described, but the most recognized cause is the effect of cumulative microtrauma that results from repetitive wrist extension and alternating forearm supination and pronation. The healing process leads to formation of scar tissue, which is more liable to further tearing with recurrent trauma [24]. According to Khoury et al. [25], they revealed that the increase in tendon compressibility indicative of tendon softening is a novel sonographic sign of common extensor tendinopathy. Macroscopic structural changes in case of tendons such as tendon thickening, heterogeneous texture and loss of the normal fibrillary shape is usually diagnosed by ultrasound. Studies have shown that in the early stage of the tendinosis, tendons may look normal macroscopically in patients

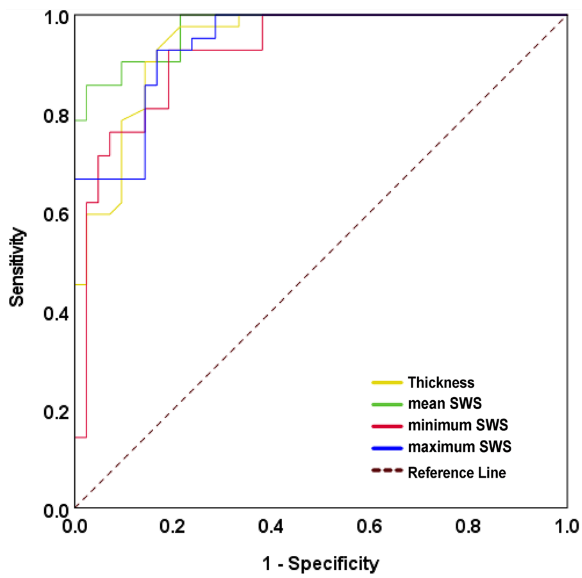

Fig. 5 Area under the curve (AUC) values according to the cutoff values

Table 4 Sensitivity, specificity, and AUC values based on cutoff values

	Cutoff	Sensitivity (%)	Specificity	AUC (95% CI)
Thickness	≥ 4.85	90.5	85.7	0.941 (0.895–0.988)
Mean SWS	≤ 10.72	90.5	90.5	0.973 (0.947–1.000)
Minimum SWS	≤ 9.46	92.9	81.0	0.924 (0.867–0.981)
Maximum SWS	≤ 12.51	92.9	83.3	0.942 (0.897–0.986)

SWS shear wave speed, *AUC* area under the curvel, *CI* confidence interval

with symptoms, and therefore, the most suitable imaging modality is the quantitative one that gives information about the viscoelastic property of a tendon [14].

A study conducted by Kocyigit et al. [15] has shown that real-time sono-elastography findings were greater than B-mode US and color Doppler US findings in differentiating healthy from involved elbows which were compatible with our results where SWE could directly reflect quantitatively the effect of lateral epicondylitis on CET. In a study conducted by Hackett et al. [13], it showed lower shear wave velocity measurements; therefore, reduced tissue stiffness in tendinopathic supra-spinatos tendons when compared to normal tendons using shear wave sonoelastography. Therefore, they concluded that this imaging tool was reliable to evaluate the supra-spinatos tendon. Hence we could use the same technique for evaluation of tissue stiffness of CET in lateral epicondylitis patients.

Our study also revealed that both the tendon thickness and the shear wave speed were higher significantly in patients following the non-operative therapy than prior to it. To our knownledge, a single previous study has evaluated the contribution of the shear wave elastography in follow-up of cases with elbow lateral epicondylitis post therapy [18]. Nevertheless, our result, in accordance with the study made by Zhu et al. [18], demonstrated that shear wave elastography (SWE) could not only help establishing a diagnosis of the lateral epicondylitis but it could also help following up the efficiency of therapy.

Both the intra-rater and inter-rater agreements were evaluated in this study. Measured values of shear wave elastography for CET obtained excellent ICCs (values of ICCs extended from 0.939 to 1 for mean SWS, minimum SWS, and maximum SWS). The high intra- and inter-observer agreements indicate that this technique is a reproducible one for the evaluation of CET and rarely dependent on the operators. Sendur et al. [16] applied SWE to evaluate the normal CET stiffness and showed a significant interobserver agreement. Zhu et al. [18] also found a high intraobserver and interobserver agreement in evaluation of SWE in unilateral lateral epicondylitis. Nevertheless, they suggested that the measurements of both observers were almost equal due to the application of the similar technique and same knowledge tools, this is possibly why they reached excellent ICCs. Consequently, the standardized operating technique renders shear wave elastography (SWE) dependable and practical to evaluate the lateral epicondylitis.

The mean SWS with a value of ≤ 10.72 m per second (m/s) revealed the highest area under the curve among the tendon thickness, the mean, the minimum and the maximum shear wave speeds, with a sensitivity and specificity of 90.5%.

According to a review article managed by Karanasios et al. [26], under the title "Diagnostic accuracy of examination tests for lateral elbow tendinopathy", Gray-scale ultrasound showed a sensitivity between 53 and 98% and a specificity between 42 and 90%. When tissue elasticity through color-coded mapping was added using transient, strain or shear wave elastography, both sensitivity and specificity were reported to be very high, ranging from 75 to 100% and 85 to 96%, respectively.

We had several limitations in our study. First, we did not evaluate the three sections of common extensor tendon, but we only evaluated a single location where the lesion was, unlike other previous studies [4]. Another limitation was the small study population. Additionally, our study did not study the correlations between shear wave elastography, clinical examination, clinical outcome or the variable tendinopathy features in gray-scale ultrasound. Only correlations concerning tendon thickness and shear wave elastography were implemented. Further future studies investigating the relation among these different evaluation methods are essential.

Conclusions

In our study, the shear wave speed of CET was reduced when assessed by shear wave elastography in elbows with lateral epicondylitis, compared to the contralateral healthy elbows, and it improved following non-operative management. The excellent intra-rater and inter-rater agreement shows that shear wave elastography is a feasible and reliable tool for the assessment of common extensor tendon. Additionally, the area under the curve, sensitivity and specificity of shear wave elastography were high in diagnosing lateral epicondylitis. In conclusion, SWE can be used as a technique with high reproducibility and proper diagnostic accuracy for evaluation and monitoring the therapeutic effect in patients with lateral epicondylitis. Future studies involving a larger population size and a correlation between shear wave speed, clinical examination and gray-scale ultrasound may be of value.

Abbreviations

LE: Lateral epicondylitis; CET: Common extensor tendon; MRI: Magnetic resonance imaging; US: Ultrasound; SWEUS: Shear wave elastography ultrasound; ARFI: Acoustic radiation force impulse; m/s: Meter per second; SWS: Shear wave speed; ROI: Region of interest; SD: Standard deviation.

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Author contributions

MI: Conceived the study, designed it, was the primary radiologist who interpreted the images blindly from the second radiologist, and drafted the manuscript. ME: Participated in the design of the study, revised and adjusted the manuscript. MR: Was the orthopedic surgeon who made the clinical examinations and revised the orthopedic part of the manuscript. All authors have read and approved the final version of the manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study had been approved by the Research Ethics Committee of the Faculty of Medicine at Cairo University in Egypt on 201672016; in compliance with Helsinki Declaration (DoH-oct20081). All patients included in this study gave written informed consent to participate in this research. If the patient was less than 16 years old or unconscious at the time of the study, written informed consent for their participation was given by their parent or legal guardian.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study. If the patient was less than 16 years old, deceased, or unconscious when consent for publication was requested, written informed consent for the publication of this data was given by their parent or legal guardian.

Competing interests

The authors declare that they have no competing interests.

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