

## Association of real-time sonoelastography findings with clinical parameters in lateral epicondylitis

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**Abstract** The objective of this study was to investigate the role of real-time sonoelastography (RTSE) in patients with lateral epicondylitis (LE) and whether it is associated with clinical parameters. Seventeen patients with unilateral LE were enrolled in the study. The healthy elbows of the participants constituted the control group. Using B-mode ultrasound, color Doppler ultrasound, and RTSE, we prospectively examined 34 common extensor tendon elbows of 17 patients. Both color scales and strain ratio were used for evaluating RTSE images. Two radiologists evaluated the RTSE images separately. Elbow pain was scored on a 100-mm visual analog scale (VAS). Symptom duration and the presence of nocturnal pain were questioned. Quick disabilities of arm shoulder and hand (DASH) Questionnaire was applied to assess the pain, function, and disability. Nottingham health profile (NHP) was used to determine and quantify perceived health problems. Both color scales and strain ratios of the affected tendon portions were significantly different from that of healthy tendons ( $p < 0.001$ ). There was no significant association between NHP, VAS, Quick DASH scores, and color scales and strain ratio. Strain ratio of the medial portion of the affected tendon was significantly correlated with symptom duration ( $\rho = -0.61$   $p = 0.010$ ) and nocturnal pain ( $\rho = 0.522$   $p = 0.031$ ). Interobserver agreement was substantial for color scales ( $\kappa = 0.74$ ,

$p = 0.001$ ) and strain ratio ( $\text{ICC} = 0.61$ ,  $p = 0.031$ ). RTSE may facilitate differentiation between healthy and affected elbows as a feasible and practical supplementary method with substantial interobserver agreement. RTSE was superior to B-mode ultrasound and color Doppler ultrasound in discriminating tendons with LE. Strain ratio of the medial portion of the tendon is associated moderately with nocturnal pain and symptom duration. No other associations were present between RTSE findings and clinical or functional parameters.

**Keywords** Musculoskeletal disease · Elbow joint · Ultrasound · Quality of life

### Introduction

Lateral epicondylitis (LE) is a common source of lateral elbow pain with an estimated prevalence of 1–3 % [1]. This overuse syndrome is associated with repetitive and/or forceful hand tasks and typically affects the dominant arm. Prevalence of LE increases to more than 50 % in tennis players, a population that uses regular repetitive hand functions [2]. The diagnosis is made clinically through history and physical examination [3]. Furthermore, magnetic resonance imaging (MRI) and ultrasound (US) findings may provide information on differential diagnosis and disease severity [4, 5].

Ultrasound elasticity imaging is relatively new noninvasive, ultrasound-based imaging method that provides information on the mechanical properties of tissues (stiffness and elasticity), reflecting their quality. There are two different types of ultrasound elasticity imaging: real-time strain elastography (RTSE) and shear-wave elastography (SWE). RTSE displays the subjective distribution of strain caused

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by tissue compression, whereas SWE measures the intrinsic tissue elasticity using the acoustic push-pulse. Both RTSE and SWE have been used to evaluate different musculoskeletal disorders [6].

RTSE is based on the principle that tissue deforms due to the stress from the ultrasound transducer. Strain is defined as the amount of displacement from the probe. Strain differs between tissues and lesions according to their elastic properties. Soft tissues deform more while stiff tissues deform less. Specific software systems convert the computed strain to color codes that represent different degrees of elasticity during RTSE. Lesions affecting the elasticity of tissue can be distinguished by RTSE as altered areas of stiffness [6].

RTSE is considered as a promising method to determine the stiffness of various musculoskeletal structures. It has been applied to patients with lateral epicondylitis in recent studies [7, 8]. De Zordo et al. [7] reported that RTSE findings were valuable in the detection of alterations in lateral epicondylitis. Ahn et al. [8] evaluated the feasibility of RTSE as an objective method for assessing patients with lateral epicondylitis. They reported significant strain ratio difference in patients with lateral epicondylitis. However, to the best of our knowledge, there is no prior study regarding the association between clinical parameters and RTSE findings.

The objective of our study is to assess the sonoelastographic changes on the common extensor tendon in patients with lateral epicondylitis and investigate whether RTSE findings correlate with clinical parameters.

## Materials and methods

The procedures followed in this study were in accordance with the ethical standards of Helsinki Declaration. The study was approved by the institutional ethics committee, and each patient gave written informed consent.

We performed power analysis for the sample size estimation. Setting type I error ( $\alpha$ ) at 0.01 and power of the test at 0.95, we calculated sample size appropriate to test the hypothesis and have confidence as 31. Number of elbows to ensure that final sample size is achieved was calculated to be 34 when the proportion of attrition is accepted as 10 %.

## Subjects

Twenty-one patients who were presented to the institutional outpatient clinic with a primary complaint of unilateral elbow pain were scrutinized for enrollment in the study to reach the estimated allocation number from January 2015 to April 2015. Two patients who had a history of corticosteroid injection to treat LE in

the previous 3 months were excluded. One patient with rheumatoid arthritis was also excluded. One patient did not come for the scheduled RTSE examination and was excluded. Finally, data of 34 elbows of 17 patients were analyzed. We used ultrasound, color Doppler ultrasound, and RTSE to examine prospectively 34 common extensor tendons in both elbows of 17 patients. The healthy elbows of the participants constituted the control group. The inclusion criteria for the involved elbow were unilateral elbow pain diagnosed as lateral epicondylitis according to physical examination findings, age between 18 and 65 years, and approval of inclusion in the study. The inclusion criteria for the healthy elbow were the absence of elbow pain, no limitation of elbow range of motion, and the absence of tenderness at lateral epicondyle. The exclusion criteria were history of previous elbow fracture/surgery, history of corticosteroid injection for elbow pain, acquired or congenital elbow deformity, elbow osteoarthritis, inflammatory joint disease, peripheral vascular disorder, corticosteroid or estrogen medication.

Patients were diagnosed as lateral epicondylitis if palpation of the common extensor origin and resisted wrist extension were painful [9]. A thorough physical and neurological examination was conducted to rule out other clinical conditions that can cause elbow pain. Elbow pain was evaluated on a 100-mm visual analog scale (VAS). We measured pressure pain threshold in kilograms, at the most tender soft tissue of the lateral epicondyle with pressure algometer (Wagner Pain Test™ Model FPK 40 Algometer, Wagner Instruments, Greenwich, CT, USA).

Quick DASH (disabilities of arm shoulder and hand) Questionnaire was applied to evaluate the pain, function, and disability. Quick DASH is an abbreviated version of the original DASH outcome measure. In comparison with the original 30 item DASH outcome measure, the Quick DASH only contains 11 items [10]. It is a questionnaire that measures the severity of symptoms, ability to complete tasks and absorb forces. Quick DASH tool uses a five-point Likert scale from which the patient can select an appropriate number corresponding to his/her severity level/function level [11]. The reliability and validity of a Turkish version of Quick DASH were reported in 2011 [12].

Nottingham health profile (NHP) is a self-administered questionnaire that is used to determine and quantify perceived health problems. It is divided into six subscales (sleep, mobility, energy, pain, emotional reactions, and social isolation) and consists of 38 items [13]. Validity and reliability of the Turkish version were documented in 2000 [14].

After these preliminary clinical and functional evaluations, B-mode US, color Doppler US, and RTSE examinations of both elbows were performed.

## Ultrasound imaging

A high-resolution ultrasound device (Logiq E9, GE Healthcare, Milwaukee, Wisconsin, USA) equipped with an elastography-compatible 9–15 MHz matrix linear probe was used to scan common extensor tendons of both elbows. All sonographic examinations were performed by the same radiologist (AK) who was blinded to the involved side of the patient.

All subjects were examined while seated and facing the examiner with both elbows in semiflexion. The probe was placed in the longitudinal plane over the lateral epicondyle along the common extensor tendon. The probe was positioned parallel to the common extensor tendon to avoid anisotropy when performing the conventional US and to prevent tissue-shifting when performing RTSE. The entire tendon origin from the anterior edge to the posterior edge was scanned during ultrasound.

The common extensor tendinous origin from the lateral humeral epicondyle was examined in longitudinal and axial planes during B-mode US. Five ultrasound criteria were investigated on B-mode US: (1) echotexture, (2) intrasubstance tears, (3) presence of lateral collateral ligament (LCL) rupture, (4) swelling, and (5) calcification. We evaluated echotexture by identifying areas of hypoechogenicity within the tendon. Discrete tears within the tendon were identified as focal areas of anechoic change, an anechoic area without intact fibers or hypoechoic planes of fibril discontinuity. A focal discontinuity of the echogenic band between the radius and lateral capitellum was defined as LCL tear that can be partial or full thickness. Swelling was defined as outward convexity of the tendon origin.

We used color Doppler US to evaluate intratendinous hyperemia. Intratendinous hyperemia was defined as a color-flow signal in the common extensor tendon origin, and color Doppler US settings were adjusted to maximize the sensitivity to low-velocity and low-volume blood flow (Fig. 1). The color Doppler US gain was optimized with an increase in gain until noise appeared, and the gain was then reduced slightly to suppress the noise as defined by Breidahl [15].

RTSE was performed focusing on the areas with abnormal findings on B-mode US. Tendinous abnormalities were divided into three sections: the anterior, middle, and posterior fibers as defined by Connell et al. [16]. At least three scans of each tendon third were performed. During RTSE examination, manual light compression and decompression of the common extensor tendon by the probe were performed attentively to achieve an optimal and consistent color coding shown on the sonography screen. The force applied to the tendon was adjusted appropriately according to the visual indicator seen on the US display. The visual indicator is a bar scale of 1–7 that showed optimal strain at

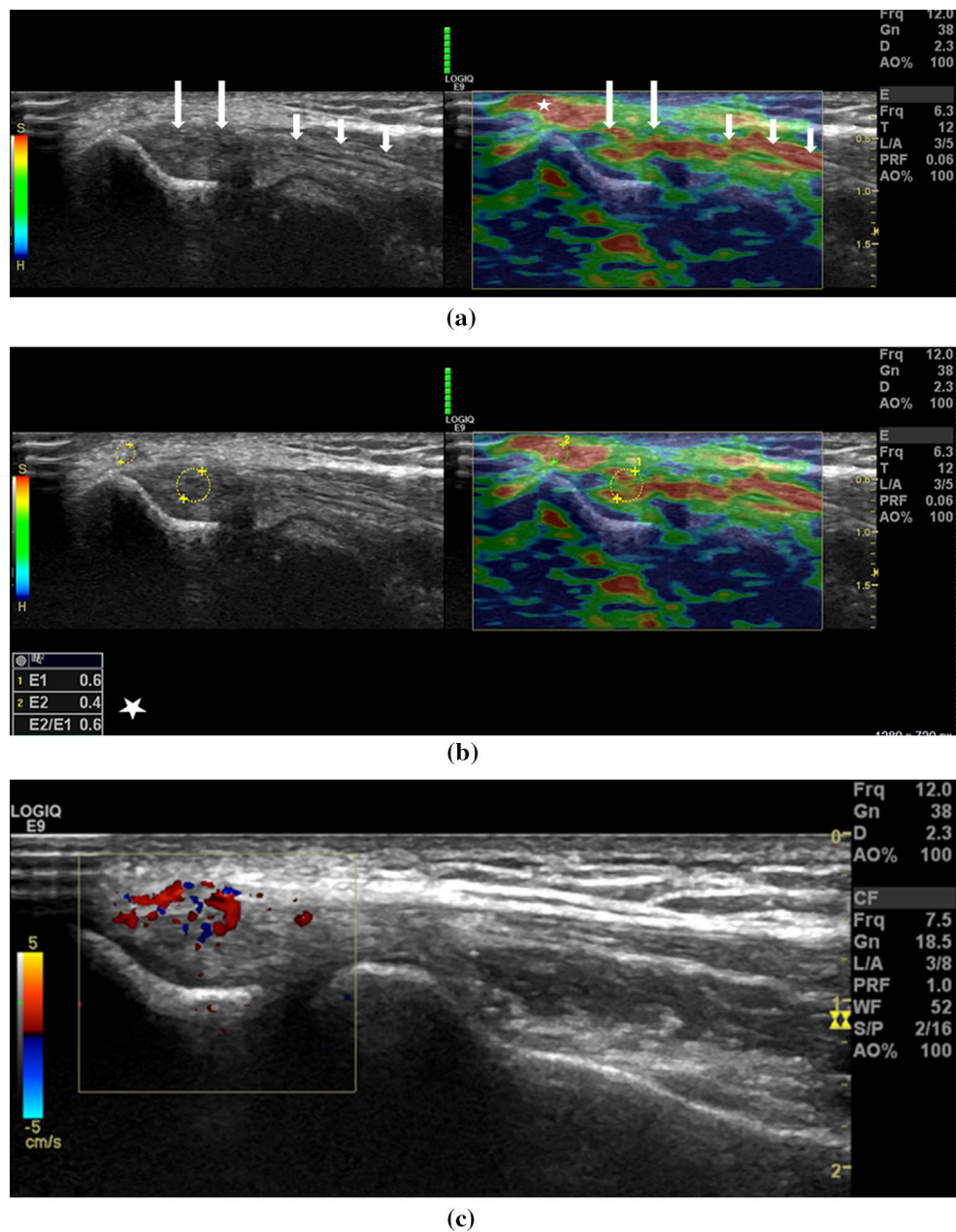
the region of interest. The radiologist evaluated the images having adequate compression when the bar scale was 5–7. Each RTSE scan was repeated by compression and relaxation of the scan area several times (at least three compression–decompression cycles) until the findings were confirmed to be reproducible as defined by De Zordo et al. [17]. RTSE and B-mode US images were simultaneously displayed as a two-panel image. All the RTSE images were recorded by the ultrasound device digitally and also sent to the local picture archiving and communication system (PACS) for later evaluation and statistical analysis. RTSE images were evaluated 1 month later by two radiologists (AK and DTH) individually to investigate the interobserver agreement. Both radiologists had 10-year experience in ultrasound and 2-year experience in RTSE. The radiologists were blinded to the involved side of the patient during evaluation. Both researchers evaluated the color scale and calculated strain ratios on recorded images.

For the qualitative color scaling, a visual grading in which the relative stiffness of the tissues ranged from red (soft) to blue (stiff) was used [18]. Blue color represented stiff areas. Green or green-yellow and red or orange-red colors represented moderately and severely softened areas, respectively.

Strain ratio was calculated using the ratio of the strain in the small circular region of interest (ROI) in the adjacent subcutaneous tissue (E2) to that of the target area (common extensor tendon [E1]). The selection of the reference ROI is a factor that can have a significant impact on the strain ratio measurements [19]. We selected the reference ROI at the subcutaneous fat tissue near the common extensor tendon origin. Because the muscle was more distant from the target area, it was more likely to be influenced by uneven compression from the transducer, considering the curved surface of the lateral elbow. In contrast, the nearby fat was more likely to be compressed with the same strength and in the same direction as the target structure. We expected this method of ROI selection would compensate for uneven compression provided by the operator in part. The mean strain ratio (E2/E1) was computed by the software. A higher strain ratio indicated decreased stiffness in the affected common extensor tendon (Figs. 1, 2).

## Statistical analysis

Standard descriptive statistics was used to summarize characteristics of the participants including means and standard deviations (SD) of all continuous variables and counts and percentages for the categorical variables. A paired sample *t* test was used to compare objective outcomes. We calculated the area under the ROC curve for RTSE, B-mode US and color Doppler US findings. The area under the ROC curve was categorized as follows: <0.6: worthless, 0.0–0.7:



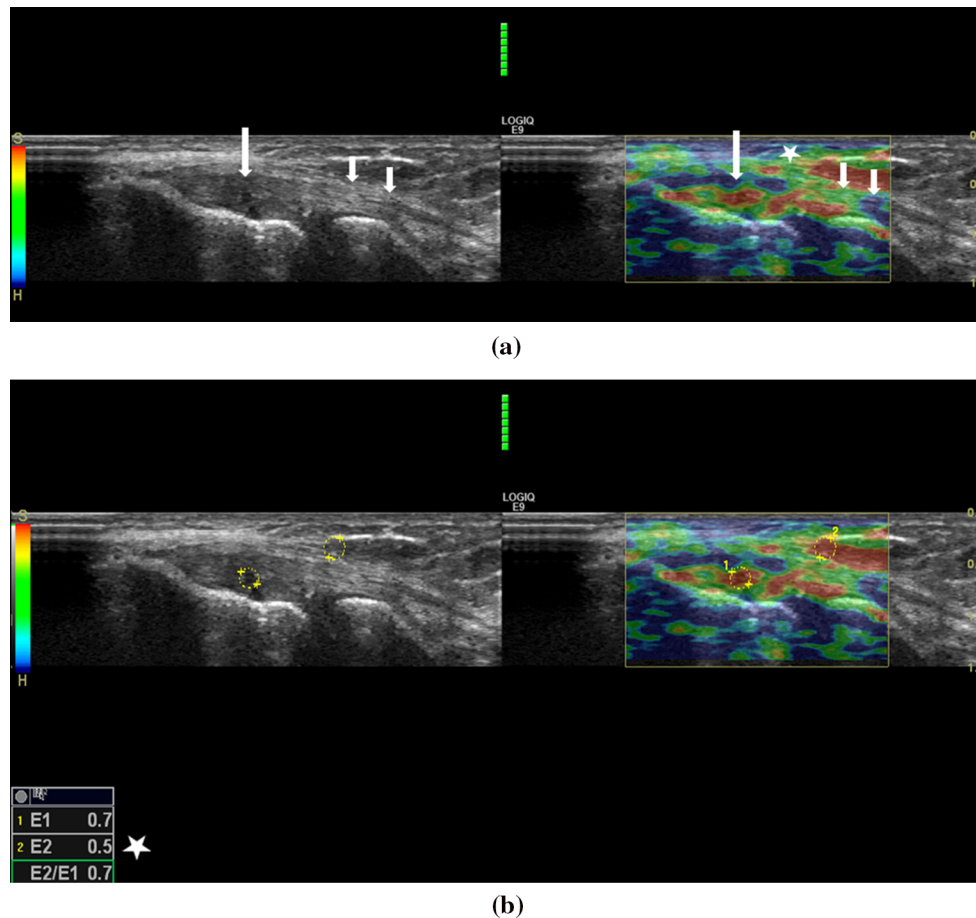
**Fig. 1** **a** Thirty-six-year-old man with lateral elbow pain. On the *left* side B-mode sonography image and on the *right* side elastography image seen together. Real-time sonoelastography shows focal *red-coded* areas (*long arrows*) in symptomatic common extensor tendon. Subcutaneous fat is coded *red* to *bright green* color (*asterisk*), and the distal portion of the tendon is in *red* to *green* color (*short arrows*). Artifacts are shown as *red* and *green* areas inside the bone and are present on all real-time sonoelastographic images. **b** The elastographic ratio is also calculated by selection of two regions of interest

(ROIs) on elastography image. First ROI is placed on the tendon and includes *red-coded* area (marked as 1). Second ROI is placed on subcutis, above common extensor tendon as reference area (marked as 2). Mean elastographic ratio (E2/E1) is instantly computed and displayed on the bottom *left* side of the screen (*asterisk*). In this symptomatic tendon, the mean elastographic ratio was 0.6. **c** Color Doppler sonography image demonstrates vascularisation of the common extensor tendon of the same patient

poor, 0.71–0.80: fair, 0.81–0.9: good, and 0.91–1: excellent [20]. Spearman correlation coefficient ( $\rho$ ) was used to compare color scaling and strain ratio with age, gender, symptom duration, VAS, and Quick DASH score. Cohen's kappa ( $\kappa$ ) coefficient was used to evaluate interobserver

agreement for color scaling of RTSE images. Interclass correlation coefficient (ICC) was used to assess interobserver agreement for the strain ratio measurements. Interobserver agreement was categorized as follows: 0–0.20, poor; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial;





**Fig. 2** **a** Forty-two-year-old woman with lateral elbow pain. On the *left* side B-mode sonography image and the *right* side elastography image seen side by side. Real-time sonoelastography shows focal red-coded areas (long arrows) in symptomatic common extensor tendon. Subcutaneous fat is coded red to bright green color (asterisk), and the distal portion of the tendon is in green to blue color (short arrows). Artifacts are shown as red and green areas inside the bone and are present on all real-time sonoelastographic images. **b** The elas-

tographic ratio is also calculated by selection of two regions of interest (ROIs) on elastography image. First ROI is placed on the tendon and includes red-coded area (marked as 1). Second ROI is placed on subcutis, above common extensor tendon as reference area (marked as 2). Mean elastographic ratio (E2/E1) is instantly computed and displayed on the bottom left the side of the screen (asterisk). In this symptomatic tendon, mean elastographic ratio was 0.7

and 0.81–1.00, almost perfect [21]. A  $p$  value  $<0.05$  was considered statistically significant. Statistical analysis was performed with SPSS software, release 21.0 (SPSS Inc., an IBM Company, and Chicago, IL, USA).

## Results

Of the 17 participants, 10 were males (55 %) and 7 were females (44 %). The mean age was  $47.8 \pm 10.6$  years (range 35–69 years). Other demographic parameters are shown in Table 1. The mean symptom duration was  $89 \pm 77$  days (range 5–240 days).

The mean VAS for pain was  $50 \pm 23$  mm (range 5–81 mm); the mean Quick DASH score was  $33.2 \pm 19.8$  points (range 7.5–75). The mean NHP physical activity

score was  $11.9 \pm 11.7$  (0–31.29), and the mean NHP total score was  $150.06 \pm 100.83$  (12.01–333.32).

In healthy elbows, LCL involvement was detected in one elbow (5.9 %) as swelling. B-mode US findings and color Doppler US findings were in normal range. The overlying fascia was not involved in any of the healthy elbows. None of the elbows had calcification.

In elbows with lateral epicondylitis, 35.3 % (6/17) of tendon thirds were normal, 41.2 % (7/17) had one focal lesion, 17.6 % (2/17) had two focal lesions, and 5.9 % (1/17) had more than two focal lesions on B-mode US. Symptomatic LCL involvement was found in 29.4 % (5/17) of the elbows with lateral epicondylitis. The color Doppler US documented intratendinous hyperemia in 41.7 % (7/17) of the involved elbows. Calcification was present in 5.9 % (1/17) of the patients.

**Table 1** Demographic and clinical parameters of the study group

Demographic parameter	Number (%)
Educational status	
Primary school or less	10 (55)
Elementary school	2 (12)
High school and more	5 (33)
Employment status	
Present employee	9 (52)
Unemployed	4 (24)
Retired	4 (24)
Presence of comorbidities	
None	13 (77)
Only one comorbidity	3 (18)
>1 comorbidities	1 (5)
Hand dominance	
Right	16 (94)
Left	1 (6)
Involvement	
Right	13 (77)
Left	4 (23)
Presence of nocturnal pain	
Yes	11 (61)
Presence of functional impairment	
Yes	14 (83)
Total	17 (100)

In healthy elbows, RTSE showed stiff tendon structures, corresponding to blue coloring, in 74.5 % (39/51) of common extensor tendon thirds (Fig. 3). Green or green-yellow color scaling was detected in 17.6 % (9/51), and red or orange-red colors were present in 5.8 % of the tendon sections (3/51).

The area under an ROC curve quantifies the overall ability of the test to discriminate between those individuals with the disease and those without the disease. The area under the ROC curve analysis was as follows: medial portion of tendon color scaling: 0.933 medial portion of tendon strain ratio: 0.917, middle portion of tendon color scaling: 0.903 middle portion of tendon strain ratio: 0.843 lateral portion of tendon color scaling: 0.884 lateral portion of tendon strain ratio: 0.863 B-mode US: 0.735 color Doppler US: 0.794.

The interobserver agreement was substantial for both color scaling ( $\kappa = 0.74$ ,  $p = 0.001$ ) and strain ratio (ICC = 0.61,  $p = 0.031$ ) measurement. We used data reported by AK in statistical analysis. Green or green-yellow color scaling was detected in 15.7 % (8/51), and red or orange-red colors were present in 74.6 % of the tendon sections (39/51). At RTSE, the mean strain ratios in the affected elbow and healthy elbow are presented in Table 2. Statistical analysis of RTSE color scales

( $p < 0.001$ ) and strain ratios ( $p < 0.001$ ) showed a significant difference between the involved and healthy elbows (Table 2).

Regarding Spearman analysis for color scales and functional test scores, VAS, and nocturnal pain, no association between color scales and VAS, and Quick DASH score was found. When Spearman analysis for strain ratio and functional test score, VAS, and nocturnal pain was performed, there was a moderate association between strain ratio of medial portion of the extensor tendon and nocturnal pain ( $\rho = 0.522$ ,  $p = 0.031$ ) and symptom duration ( $\rho = -0.61$ ,  $p = 0.010$ ) (Table 3).

Interobserver agreement for color scale evaluation was rated as substantial ( $\kappa = 0.74$ ,  $p = 0.001$ ). Interobserver agreement for strain ratio measurement was also rated as substantial (ICC = 0.61,  $p = 0.001$ ).

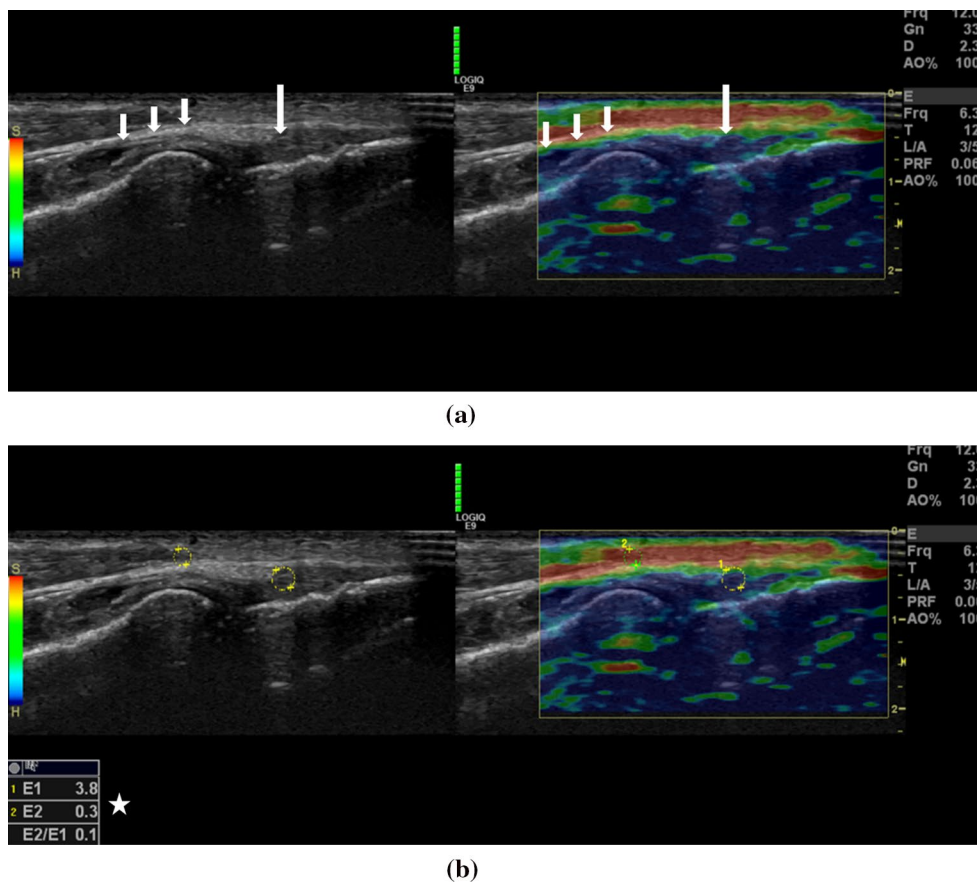
## Discussion

Our RTSE results show significantly decreased elasticity and increased strain ratios in elbows with lateral epicondylitis compared to healthy elbows. Strain ratio of the medial compartment of common extensor tendon was significantly correlated with nocturnal pain and symptom duration in our study.

Lateral epicondylitis is the most commonly diagnosed tendinous elbow disorder with prevalence ranging from 1 to 3 % in the general population. However, the prevalence can be as high as 40 % in tennis players. Anatomically, the normal common extensor origin is composed of longitudinal fibrils bound closely, with the extensor carpi radialis brevis (ECRB) constituting most of the deep fibers and the extensor digitorum making up the superficial part. The accepted cause is tendon injury often secondary to minor and/or repetitive and even unrecognized trauma. This causes disruption of the internal structure of the tendon and degeneration of the cells and matrix, which ultimately leads to macroscopic tears and tendon failure.

Diagnosis of lateral epicondylitis is often made clinically, depending on the history and physical examination findings [9]. When the symptoms are confounding or refractory, imaging is often used to confirm the diagnosis and exclude other entities [21]. MRI has been shown to be sensitive for tendon lesions; however, ultrasound, with superior spatial resolution, is increasingly used as an alternative to MRI [16, 22, 23]. Ultrasound can also assess severity with a progression suggested from hypoechogenicity (representing fibroblastic degeneration) to intrasubstance tears and partial-thickness tears.

Focal or diffuse areas of low echogenicity, increased thickness and outward bowing of the tendon, the presence of peri tendinous fluid, intratendinous calcifications, and



**Fig. 3** **a** Forty-seven-year-old woman with a normal elbow. On the *left* side B-mode sonography image and the *right* side elastography image seen together. Real-time sonoelastography shows *blue to green* color (*long arrows*) in normal common extensor tendon. Subcutaneous fat is coded *red to bright green* color, and the distal portion of the tendon is in *green to blue* color (*short arrows*). Artifacts are shown as *red and green* areas inside the bone and are present on all real-time

sonoelastographic images. **b** The elastographic ratio is also calculated by selection of two regions of interest (ROIs) on elastography image. First, ROI is placed on the normal tendon (marked as 1). Second ROI is placed on subcutis, above common extensor tendon as reference area (marked as 2). Mean elastographic ratio (E2/E1) is instantly computed and displayed on the bottom *left* side of the screen (*asterisk*). In this normal tendon, the mean elastographic ratio was 0.1

**Table 2** Physical examination and imaging findings of the involved and healthy elbow

Parameter	Elbows with lateral epicondylitis	Healthy elbows	<i>p</i> value
Lateral epicondyle tenderness <sup>a</sup>	17	0	<0.001
Lateral epicondylitis test <sup>a</sup>	17	0	<0.001
Medial epicondyle tenderness	6	3	0.184
Pressure pain threshold (kg)	5.2 ± 1.6	7.9 ± 2.5	<0.001
Color scale <sup>b</sup>			
Medial portion	16	3	<0.001
Middle portion	16	4	<0.001
Lateral portion	15	5	<0.001
Strain ratio (mean ± SD)			
Medial portion	0.45 ± 0.12	0.18 ± 0.13	<0.001
Middle portion	0.44 ± 0.8	0.21 ± 0.13	0.001
Lateral portion	0.47 ± 0.19	0.20 ± 0.14	<0.001

SD Standard deviation

<sup>a</sup> Presented as number of patients with positive physical examination finding/test result

<sup>b</sup> Presented as number of patients with affected color scale (green, yellow, red)

**Table 3** Correlation analysis results between strain index, color scaling and clinical and demographic parameters

Parameter	Common extensor tendon color scaling						Common extensor tendon strain ratio					
	Medial		Middle		Lateral		Medial		Middle		Lateral	
	$\rho$	$p$	$\rho$	$p$	$\rho$	$p$	$\rho$	$p$	$\rho$	$p$	$\rho$	$p$
Age	-0.20	0.43	-0.14	0.58	-0.37	0.89	0.1	0.70	-0.24	0.35	0.11	0.68
Gender	0.44	0.86	0.87	0.74	0.41	0.10	0.32	0.22	-0.62	0.81	0.35	0.17
Symptom duration	-0.41	0.1	-0.46	0.65	0.15	0.56	-0.61	0.01*	-0.21	0.43	-0.1	0.71
VAS	-0.22	0.39	-0.17	0.52	0.11	0.67	-0.12	0.64	0.61	0.82	0.01	0.98
Nocturnal pain	0.27	0.30	0.24	0.39	0.15	0.29	0.52	0.03*	0.17	0.52	0.41	0.10
Pain threshold	0.36	0.19	0.32	0.24	0.12	0.68	0.35	0.2	0.24	0.39	0.45	0.87
Quick DASH Score	-0.22	0.34	-0.15	0.56	-0.95	0.72	-0.22	0.38	-0.06	0.82	0.41	0.10
NHP total score	0.57	0.19	0.32	0.24	0.12	0.68	-0.4	0.11	-0.23	0.38	-0.19	0.47

$\rho$ , Spearman's correlation coefficient;  $p$ ,  $p$  value, VAS visual analog scale, DASH disabilities of arm shoulder and hand, NHP Nottingham health profile

\*  $p < 0.05$  was accepted statistically significant

adjacent bone irregularities, LCL tears have been reported as various sonographic findings in lateral epicondylitis [4, 16, 24]. In the current study, focal hypoechogenicity of the tendon was the most common finding, followed by swelling, with calcification being least frequent.

Khoury et al. [25] defined increased tendon compressibility indicative of tendon softening as a new sonographic sign of common extensor tendinopathy. In this regard, estimation of tissue softening can be a useful tool for characterization of an intratendinous pathologic finding such as tendinosis. De Zordo et al. [7] reported RTSE findings in lateral epicondylitis. Their results showed that RTSE facilitates differentiation between healthy and symptomatic extensor tendon origins with excellent sensitivity.

Elastography is the estimation of tissue strain. MRI and US can be used for elastography. RTSE produces rapid results in real time. Moreover, recent studies reported moderate to substantial interobserver agreement [8]. However, only the semiquantitative strain ratio can be measured, which requires a reference ROI. We used the subcutaneous tissue as a reference ROI in our study.

Qualitative color scaling or semiquantitative strain ratio can be used when interpreting RTSE findings, former being a more preferred method. Strain ratio values have been reported in various previous studies. Lyshchik et al. [26, 27] described the strain ratio of the thyroid gland to the tumor and the strain ratio of the neck muscle to a cervical lymph node. Drakonaki et al. [28] measured the strain ratio of the normal Achilles tendon using the Kager fat pad as a reference. Kocyyigit et al. [29] reported increased strain ratio in a patient with plantar fasciitis. They suggested that sonoelastographic strain ratio may document the early structural changes that occurred in the affected tissue before findings can be detectable by conventional imaging in the early diagnosis of plantar fasciitis. Ahn et al. [8] used the subcutaneous fat tissue as a reference

in patients with lateral epicondylitis. However, instead of measuring the value on the selected static images, they measured the temporally averaged strain ratio to decrease selection bias and time consumption for best-fit image selection. We evaluated RTSE images by using both color scaling and strain ratio measurement. We documented that both color scaling and the semiquantitative strain ratio reliably differentiate the affected elbows from healthy counterparts in lateral epicondylitis. Furthermore, we conducted area under the ROC curve analysis. We documented that both color scaling and strain ratios of the investigated tendon parts were superior to B-mode US and color Doppler US findings in discriminating healthy from involved elbows in patients with LE.

The literature is scarce about the association of RTSE findings with clinical and functional scores. To the best of our knowledge, our study is the first to investigate this association in patients with LE. We did not observe an association between color scales and functional test scores, VAS, and nocturnal pain. Strain ratio was not correlated with VAS and functional scores either. However, the presence of nocturnal pain and symptom duration was moderately associated with strain ratio of the medial portion of the tendon. In clinical practice, the presence of nocturnal pain is accepted as a sign of severe involvement. The severity and chronicity of the disease seem to affect the stiffness of the tendon according to our results. The impairment in functional scores might not be associated with radiological findings as reported for disk herniation and osteoarthritis before [30, 31].

The strain ratios and color scales of medial, middle, and lateral tendon portions were similar in our study. However, strain ratio of a medial part of the common extensor tendon was significantly correlated with symptom duration and nocturnal pain. Connell et al. [16] reported more common involvement of medial part of the common extensor tendon than lateral and middle portions. Despite the lack



of histopathologic studies investigating the involvement of different tendon portions in patients with LE, the medial part of the tendon might be the first affected part. This may be an explanation for the association of strain ratio of the medial portion and symptom duration.

RTSE is individually performed, usually by freehand technique. Moreover, even with the same elastographic image, variable interpretations are possible among performers because of ROI selection. The size and location of the selected ROIs may be inconsistent despite precautions for standard measurement [8]. Therefore, interobserver variability is inevitable, and many previous studies have described the situation as a limitation of RTSE. Recent previous studies reported fair to moderate interobserver agreement for both color scaling and strain ratio measurement [8, 32]. We also detected substantial interobserver agreement for both color scaling and strain ratio calculation.

Acquisition of images by only one radiologist is a limitation of our study. However, it would be unethical to examine a painful patient twice with an imaging method lasting about 45 min. Therefore, one radiologist performed the examinations, and the recorded images were evaluated 1 month later separately by two radiologists.

In conclusion, our study revealed that strain ratio and color scaling are significantly different in affected elbows when compared to healthy counterparts. RTSE findings were superior to B-mode US and color Doppler US findings in discriminating healthy and involved elbows. Nocturnal pain and symptom duration was correlated with the strain ratio of the medial portion of the tendon. No other associations were present between RTSE findings and clinical or functional parameters. Our results show that RTSE could be a feasible, simple and quick diagnostic method in patients with lateral epicondylitis with substantial interobserver agreement.

#### Compliance with ethical standards

No funding or grant or equipment was provided for the project from any source. The study was approved by Pamukkale University Non-invasive Research Ethical Committee. Study number: 60116787-020/1008. Each participant gave written informed consent.

**Conflict of interest** The authors declare that there are no conflicts of interest.

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