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RESEARCH

Dynamic microvascular imaging with provocative testing in lateral epicondylitis: associations with tendon vascularity and clinical severity

Lateral epikondilitte provokatif test ile dinamik mikrovasküler görüntüleme: tendon vaskülaritesi ve klinik şiddet ile ilişkisi

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Abstract

Purpose: This study aims to investigate whether dynamic microvascular imaging (MVI) performed during mechanical provocation provides added diagnostic value in the ultrasound evaluation of lateral epicondylitis and explore its relationship with pain severity and functional impairment.
Materials and Methods: This retrospective study included 94 patients with unilateral chronic lateral epicondylitis. Each symptomatic elbow was compared with the contralateral asymptomatic elbow. All patients underwent gray-scale ultrasound, Power Doppler (PD), and MVI at rest during mechanical provocation. Common extensor tendon thickness, structural abnormalities, and intratendinous vascularity were evaluated. Pain severity was assessed using a visual analogue scale (VAS), and functional impairment was evaluated using the Patient-Rated Tennis Elbow Evaluation (PRTEE).
Results: Symptomatic elbows demonstrated significantly greater common extensor tendon thickness compared with contralateral asymptomatic elbows (5.29 ± 0.45 mm vs. 4.43 ± 0.41 mm). Structural tendon abnormalities were observed in 40.0% of symptomatic elbows. Following mechanical provocation, intratendinous vascularity increased on both modalities; however, MVI demonstrated more extensive and clearly delineated vascular signals compared with PD. Higher post-provocation vascularity grades were significantly associated with increased VAS and PRTEE scores.
Conclusion: Dynamic MVI during mechanical provocation provides additional diagnostic value beyond static ultrasound assessment in lateral epicondylitis and demonstrates meaningful associations with pain severity and functional impairment.
Keywords:. Lateral epicondylitis, musculoskeletal ultrasound, microvascular imaging, power doppler, provocative testing

Öz

Amaç: Provokatif test sırasında uygulanan dinamik mikrovasküler görüntülemenin lateral epikondilit ultrasonografik değerlendirmesinde ek tanısal değer sağlayıp sağlamadığını araştırmak ve ağrı şiddeti ile fonksiyonel kısıtlılık arasındaki ilişkiyi incelemektir.
Gereç ve Yöntem: Bu retrospektif çalışmaya tek taraflı kronik lateral epikondiliti olan 94 hasta dahil edildi. Her semptomatik dirsek, kontralateral asemptomatik dirsek ile karşılaştırıldı. Tüm hastalara istirahat halinde ve mekanik provokasyon sırasında gri-skala ultrasonografi, Power Doppler ve mikrovasküler görüntüleme uygulandı. Ortak ekstansör tendon kalınlığı, yapısal anormallikler ve intratendinöz vaskularite değerlendirildi. Ağrı şiddeti görsel analog skala (VAS) ile, fonksiyonel kısıtlılık ise Hasta Değerlendirmeli Tenis Dirseği Değerlendirmesi (PRTEE) ile değerlendirildi.
Bulgular: Semptomatik dirseklerde ortak ekstansör tendon kalınlığı kontralateral asemptomatik dirseklere göre anlamlı derecede yüksek bulundu (5,29 ± 0,45 mm'ye karşı 4,43 ± 0,41 mm). Yapısal tendon anormallikleri semptomatik dirseklerin %40,0'ında gözlendi. Provokatif test sonrasında her iki modalitede de intratendinöz vaskularite artış gösterdi; ancak mikrovasküler görüntüleme, Power Doppler'a kıyasla daha yaygın ve net sınırlı vasküler sinyaller ortaya koydu. Provokasyon sonrası yüksek vaskularite dereceleri, artmış VAS ve PRTEE skorları ile anlamlı ilişki gösterdi.
Sonuç: Provokatif test sırasında uygulanan dinamik mikrovasküler görüntüleme, lateral epikondilitte statik ultrasonografik değerlendirmenin ötesinde ek tanısal değer sağlamakta ve ağrı şiddeti ile fonksiyonel kısıtlılık arasında anlamlı ilişkiler göstermektedir.

Anahtar kelimeler: Lateral epikondilit, kas-iskelet sistemi ultrasonografisi, mikrovasküler görüntüleme, power doppler, provokatif test

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INTRODUCTION

Lateral epicondylitis, commonly referred to as tennis elbow, is a frequently encountered cause of lateral elbow pain, resulting from overuse injury of the common extensor tendon origin, most notably the extensor carpi radialis brevis. Although clinical assessment remains the cornerstone of diagnosis, musculoskeletal ultrasound (US) is widely used to support the diagnosis because of its accessibility and ability to visualize tendon pathology[1,2]. Conventional gray-scale ultrasound findings, including tendon thickening, hypoechogenicity, and focal tears, have been well described; however, their diagnostic accuracy varies widely in the literature, with sensitivity and specificity reported within moderate to high ranges[1-3].

Power Doppler (PD) imaging has been utilized to detect neovascularity within tendinopathic tendons and may provide additional diagnostic information compared with gray-scale imaging alone[4,5]. Nevertheless, the diagnostic performance of PD remains inconsistent across studies, and in many patients static Doppler imaging may fail to demonstrate pathological microvascular changes at rest[6-8]. Recent advances in Doppler-based techniques, such as advanced microvascular imaging (MVI), have demonstrated a superior ability to visualize neovascularization compared with conventional color or PD in lateral epicondylosis, suggesting improved diagnostic performance[6-8].

Despite these developments, the majority of imaging studies in lateral epicondylitis continue to focus on static assessment of tendon morphology and vascularity, without evaluating dynamic microvascular responses induced by mechanical loading or mechanical provocation. Moreover, the clinical relevance of imaging-detected vascular changes remains incompletely understood, particularly in relation to patient-reported pain severity and functional impairment. Consequently, clinically meaningful vascular responses associated with symptomatic tendons may remain undetected at rest, potentially limiting diagnostic sensitivity and clinical interpretability.

The novelty of this study lies in evaluating microvascular responses to mechanical provocation using advanced Doppler-based microvascular imaging, which has not been previously investigated in lateral epicondylitis. We hypothesized that dynamic microvascular imaging during provocation would improve vascularity detection and show stronger associations with clinical severity than static ultrasound findings. Accordingly, the aim of this study was to evaluate whether dynamic MVI performed during mechanical provocation provides added diagnostic value in patients with clinically diagnosed lateral epicondylitis and to explore its association with pain severity and functional impairment.

MATERIALS AND METHODS

Study design and sample

This retrospective study included patients who underwent musculoskeletal ultrasound evaluation with a preliminary diagnosis of lateral epicondylitis between April 2024 and May 2025. Patients aged ≥18 years with a clinical diagnosis of unilateral chronic lateral epicondylitis, defined as a symptom duration of at least 6 months, were eligible for inclusion[9,10].

Inclusion required a complete ultrasound dataset obtained during a single examination session, including B-mode imaging, PD, and MVI, with availability of both baseline and immediate post-provocation PD and MVI recordings and sufficient image quality for reliable assessment. The contralateral asymptomatic elbow served as an internal control and was examined using identical imaging protocols and machine settings[11].

Patients with bilateral lateral epicondylitis, prior elbow surgery, acute elbow trauma or fracture, systemic inflammatory or rheumatologic disease, or a history of local injection therapy within the preceding 6 months were excluded due to potential effects on tendon vascularity[12,13]. A total of 121 patients were screened. Twenty-seven patients were excluded based on predefined criteria: bilateral lateral epicondylitis (n = 8), prior elbow surgery (n = 6), acute elbow trauma or fracture (n = 5), systemic inflammatory or rheumatologic disease (n = 4), and local injection within the past 6 months (n = 4). The final analysis was conducted on 94 patients who met all inclusion criteria.

Procedure

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the local ethics committee (Approval date: 10.03.2025, decision no: 02). No additional approval number is provided by the institution. Due to the retrospective design of the study and the use of anonymized data, the requirement for informed consent was waived by the ethics committee.

This retrospective study was conducted in the Radiology Department of Medline Hospital. All ultrasound examinations were jointly performed and interpreted by an orthopedic surgeon and a musculoskeletal radiologist, each with more than 10 years of experience, in accordance with standardized institutional protocols.

Ultrasound examination

All examinations were performed using a GE LOGIQ Totus ultrasound system (GE Healthcare, Chicago, IL, USA) equipped with a 6–15 MHz high-resolution linear transducer. The common extensor tendon (CET) was evaluated on gray-scale ultrasound with the patient seated, the elbow flexed at approximately 90°, and the forearm resting in a neutral position.

CET thickness was measured at the level of the lateral epicondylar plateau in the longitudinal plane, perpendicular to the tendon fibers, using a standardized and reproducible technique. Structural tendon abnormalities were predefined and included hypoechogenicity and loss of normal fibrillar architecture on gray-scale imaging[14].

Assessment of tendon vascularity and provocation

In this study, the term 'dynamic microvascular imaging' refers to vascular assessment performed immediately after mechanical provocation rather than continuous real-time imaging during muscle contraction. Tendon vascularity was assessed using PD and MVI. PD settings were optimized for low-flow detection (low pulse repetition frequency, low wall filter, and maximal gain without background noise), and minimal transducer pressure was applied to avoid vascular compression[4]. Identical Doppler settings were used for both symptomatic and contralateral asymptomatic elbows.

MVI was performed using manufacturer-recommended presets optimized for the detection of low-velocity microvascular flow, as previously described[6-8]. Intratendinous vascularity was graded using a semi-quantitative 4-point scale (grade 0: no signal; grade 1: minimal focal signal; grade 2: moderate intratendinous signal; grade 3: marked intratendinous signal)[14].

Mechanical provocation was achieved using standardized Cozen and Maudsley tests, performed by the same examiner. Each maneuver was applied for approximately 5 seconds, and ultrasound imaging was initiated within the first 10–15 seconds immediately after completion of the provocative maneuver to capture transient microvascular responses. Baseline and post-provocation PD and MVI recordings were acquired during the same examination session[15,16]. This time interval was selected because microvascular responses induced by mechanical loading are known to peak immediately after mechanical provocation and diminish rapidly thereafter; imaging during this early window maximizes detection of transient low-flow vascular changes.

Image evaluation and reliability

All ultrasound images were independently evaluated by an experienced orthopedic and traumatology specialist and an experienced musculoskeletal radiologist. Both observers were blinded to clinical outcome measures. Discrepancies were resolved by consensus. Interobserver agreement for CET thickness measurements and vascularity grading was assessed using standard reliability methodology[17].

Statistical analysis

Statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. Data are presented as mean ± standard deviation or median (interquartile range), as appropriate. Categorical variables are presented as frequencies and percentages.

Comparisons between symptomatic and contralateral asymptomatic elbows were performed using paired statistical analyses. Paired *t* tests or Wilcoxon signed-rank tests were used for continuous variables, depending on data distribution. Ordinal vascularity scores were compared using the Wilcoxon signed-rank test. Pre- and post-provocation vascularity scores were compared using paired non-parametric analyses. Associations between post-provocation vascularity grades and clinical outcome measures, including the visual analogue scale (VAS) and the

Patient-Rated Tennis Elbow Evaluation (PRTEE), were assessed using Spearman correlation coefficients. Spearman correlation coefficients were interpreted according to conventional thresholds: values of 0.3–0.5 indicate a moderate relationship, whereas values exceeding 0.5 indicate a moderately strong relationship between variables. Interobserver reliability for ultrasound measurements and vascularity grading was evaluated using the intraclass correlation coefficient (ICC) with a two-way random-effects model for absolute agreement. A two-tailed p value of <0.05 was considered statistically significant.

RESULTS

A total of 94 patients with unilateral chronic lateral epicondylitis met all inclusion criteria and were included in the final analysis. The symptomatic elbow of each patient was compared with the contralateral asymptomatic elbow.

Table 1. Patient characteristics

Variable	Value
Number of patients	94
Age, mean ± SD (years)	38.9 ± 12.6
Female sex, n (%)	55 (58.5%)
Dominant side involvement, n (%)	61 (64.9%)
Symptom duration, median (range), months	9 (6–18)

The mean age of the patients was 38.9 ± 12.6 years, and 58.5% were female. The dominant extremity was affected in 64.9% of patients. The median symptom duration was 9 months (range, 6–18 months), consistent with the definition of chronic lateral epicondylitis (Table 1).

The mean visual analogue scale (VAS) score for pain was 6.4 ± 1.1 (range, 4–8), indicating moderate to severe pain levels. Functional impairment assessed using the Patient-Rated Tennis Elbow Evaluation (PRTEE) demonstrated a mean total score of 46.8 ± 8.7, with a median score of 47 (interquartile range, 40–52), reflecting moderate disability (Table 2).

Table 2. Clinical outcome measures

Measure	Value
VAS score, mean ± SD (range)	6.4 ± 1.1 (4–8)
PRTEE total score, mean ± SD	46.8 ± 8.7
PRTEE total score, median (IQR)	47 (40–52)

On gray-scale ultrasound, the mean common extensor tendon (CET) thickness was significantly greater in symptomatic elbows compared with contralateral asymptomatic elbows (5.29 ± 0.45 mm vs. 4.43 ± 0.41 mm, $p < 0.001$).

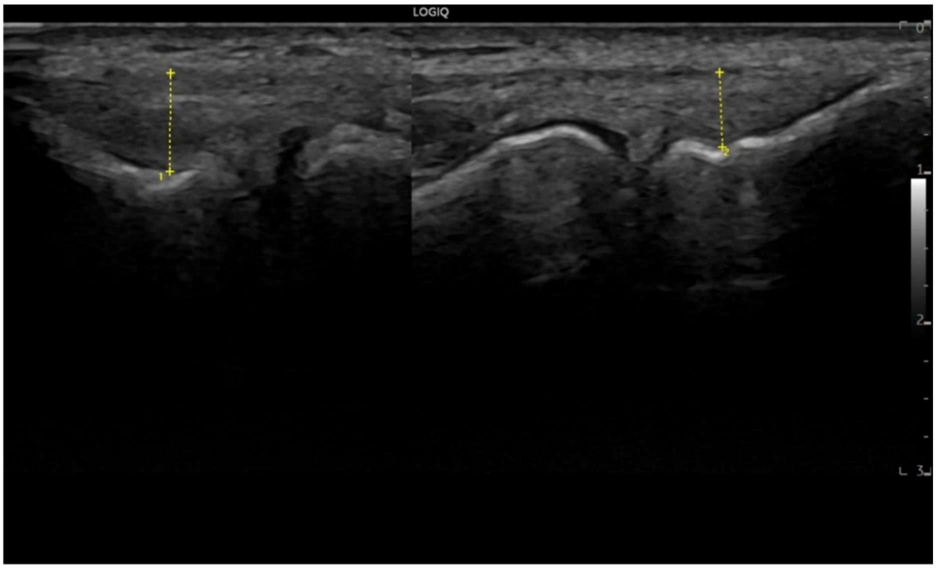

Figure 1. Sagittal B-mode ultrasonographic image of the common extensor tendon demonstrating measurement of tendon thickness at the level of the lateral epicondylar plateau. Tendon thickness was measured by drawing a perpendicular line from the tendon surface to the underlying cortical bone (yellow dashed lines).

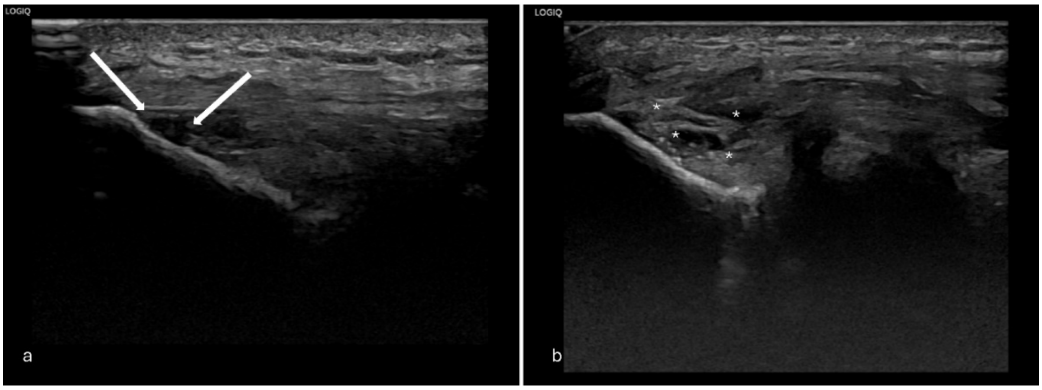

Figure 2. Sagittal B-mode ultrasonographic images of the common extensor tendon showing structural abnormalities, including a hypoechoic area consistent with mucoid degeneration (a, white arrows) and disruption of the normal fibrillar architecture (b, white asterisks).

Structural tendon abnormalities, including hypoechogenicity and loss of normal fibrillar architecture, were observed in 40.0% of symptomatic elbows, whereas no such abnormalities were detected in contralateral asymptomatic elbows (0%, $p < 0.001$) (Figure 1). At baseline, PD demonstrated intratendinous vascularity in 75.8% of symptomatic elbows, while no vascular signal was detected in contralateral asymptomatic elbows (0%, $p < 0.001$). Similarly, baseline MVI detected intratendinous vascular signals in 76.7% of symptomatic elbows compared with 0% of contralateral asymptomatic elbows ($p < 0.001$) (Figure 2).

Following mechanical provocation, a modest increase in intratendinous vascularity was observed in symptomatic elbows on both imaging modalities. Post-provocation PD positivity increased from 75.8% to 77.5%, while post-provocation MVI positivity increased from 76.7% to 78.3%.Although overall positivity rates showed only minimal changes, post-provocation MVI demonstrated more extensive and clearly delineated intratendinous vascular signals compared with PD, particularly at the tendon origin (Figure 3). The difference in positivity rates between PD and MVI did not reach statistical significance.

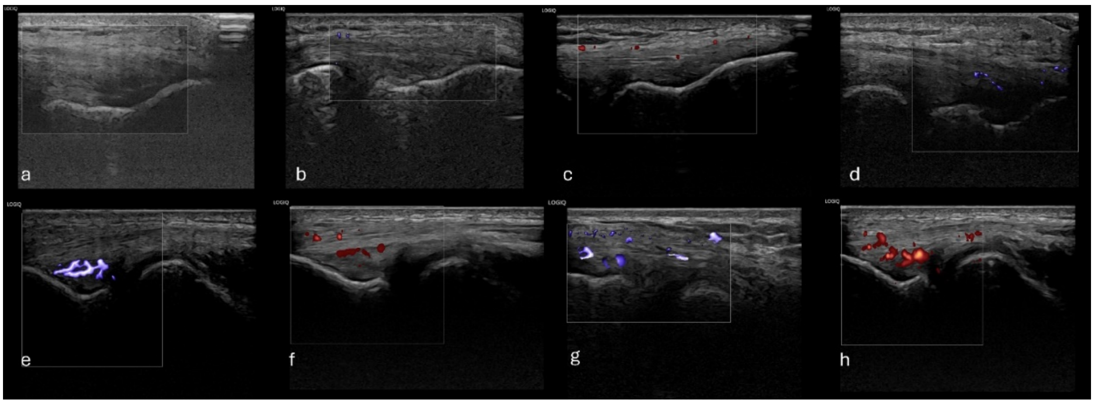

Figure 3. Representative Power Doppler (PD) and microvascular imaging (MVI) images demonstrating the semi-quantitative vascularity grading system of the common extensor tendon. Red color signals indicate Power Doppler, and blue color signals indicate microvascular imaging. (a) Grade 0; (b–c) Grade 1; (d–e–f) Grade 2; (g–h) Grade 3.

Dynamic ultrasound imaging performed during mechanical provocation allowed real-time visualization of tendon loading at the lateral epicondyle. Both Cozen and Maudsley maneuvers were associated with an immediate qualitative increase in microvascular signal intensity within the CET on MVI, most prominently at the tendon origin (Figure 4).Higher post-provocation intratendinous vascularity grades on MVI were significantly associated with increased pain severity and greater functional impairment, demonstrating moderate positive correlations with both VAS scores (Spearman's ϱ = 0.48, p < 0.001) and PRTEE scores (ϱ = 0.52, p < 0.001).

Interobserver agreement for CET thickness measurements was excellent, with an intraclass correlation coefficient (ICC) of 0.91 (95% CI, 0.88–0.94). Agreement for PD and MVI vascularity grading was good to excellent, with ICC values of 0.87 and 0.89, respectively.

Figure 4. Ultrasound-guided assessment of the lateral epicondyle during mechanical provocation. During the Cozen test (a), the patient actively performs wrist ulnar deviation and extension against resistance, with simultaneous ultrasound imaging. During the Maudsley test (b), the lateral epicondyle is evaluated during resisted middle-finger extension. Blue arrows indicate the direction of the movements actively performed by the patient during both provocation maneuvers.

DISCUSSION

The principal finding of this study is that MVI performed immediately after mechanical provocation provides clearer and more extensive visualization of intratendinous vascularity compared with static assessment alone, and that these post-provocation vascular changes are significantly associated with pain severity and functional impairment. Musculoskeletal ultrasound is widely used to evaluate lateral elbow tendinopathy because it is accessible and allows real-time visualization of tendon morphology and vascularity[1,2]. However, the diagnostic performance of ultrasound findings varies, and gray-scale abnormalities have been reported to demonstrate moderate sensitivity with relatively higher specificity depending on the feature assessed[2,3].

In the present cohort, symptomatic elbows demonstrated significantly increased common extensor tendon thickness and structural abnormalities on gray-scale ultrasound, findings consistent with the established sonographic appearance of chronic lateral epicondylitis[4,14]. From a pathophysiological perspective, lateral epicondylitis is increasingly regarded as a degenerative tendinosis rather than a purely inflammatory condition, characterized by collagen disorganization and angiofibroblastic changes as described in classic histopathologic studies[15,16]. These concepts support the use of imaging parameters that reflect not only tendon structure but also vascular behavior[17,18].

Baseline vascular assessment demonstrated intratendinous Doppler signals in symptomatic elbows with absence of detectable vascularity in contralateral asymptomatic elbows. Although neovascularity has been proposed as an imaging marker of chronic tendinopathy, static Doppler findings may be inconsistent and are not detected in all symptomatic patients at rest[19]. Previous studies have shown that PD imaging may improve diagnostic discrimination compared with gray-scale findings alone in selected cohorts with lateral epicondylalgia[20], and combined gray-scale and Doppler approaches have been evaluated in diagnostic ultrasound studies of tennis elbow[1,2].

A key contribution of the present study is the evaluation of dynamic vascular responses induced by mechanical provocation. Following provocative testing, both PD and MVI demonstrated increased intratendinous vascularity in symptomatic elbows. Although the absolute increase in Doppler positivity rates was modest, MVI consistently provided more extensive and clearly delineated low-flow intratendinous vascular signals, particularly at the tendon origin. Importantly, the added value of MVI in this study was primarily related to the improved clarity and extent of intratendinous vascular signal delineation rather than a substantial increase in positivity rates alone. Advanced Doppler-based techniques, including superb MVI, have been shown to enhance visualization of neovascularization compared with conventional Doppler methods in lateral epicondylosis and other musculoskeletal conditions[6-8]. Recent studies have similarly highlighted the diagnostic potential of advanced Doppler-based techniques in detecting low-flow neovascularization in tendinopathies, supporting the enhanced sensitivity of post-provocation microvascular imaging observed in our cohort. These findings support the concept that dynamic microvascular evaluation may reveal transient or low-flow vascular responses that can be underestimated during static resting assessments[21,22].

These observations are consistent with contemporary research demonstrating that vascular responses in chronic tendinopathy are dynamic and load-dependent, further reinforcing the clinical relevance of incorporating provocation-based imaging into routine ultrasound evaluation. Importantly, increased post-provocation intratendinous vascularity on MVI was significantly associated with higher pain intensity and greater functional impairment, as reflected by VAS and PRTEE scores. This finding suggests that provocation-related microvascular responses may be more closely linked to clinical symptom burden than static imaging findings alone. However, these results should be interpreted as associative rather than causal, given the retrospective and cross-sectional nature of the study.

From a clinical perspective, incorporating dynamic MVI into routine musculoskeletal ultrasound protocols may enhance diagnostic confidence, particularly in cases where gray-scale findings are equivocal or static Doppler imaging is negative despite typical clinical symptoms. Ultrasound also remains a practical first-line modality for excluding clinically relevant structural pathology, and prior studies have demonstrated its comparability with MRI in detecting and grading common extensor tendon tears in chronic lateral epicondylitis[5,14]. The feasibility of integrating mechanical provocation maneuvers with microvascular assessment during a single ultrasound examination, without additional equipment or patient burden, may facilitate adoption of this approach in routine clinical practice[21,23].

Several limitations should be acknowledged. The retrospective design may introduce selection bias, and the semi-quantitative nature of vascular grading, while widely used, may limit precise quantification of microvascular changes. Furthermore, longitudinal clinical outcome data were not available, which restricts the ability to determine whether post-provocation vascular responses carry prognostic significance or predict treatment outcomes. Although significant associations between vascularity and clinical severity were observed, prospective studies are required to determine whether dynamic microvascular findings have predictive or therapeutic relevance. Additionally, as this was a retrospective study based on all available patients who met the inclusion criteria within the study period, no a priori sample size calculation was performed. Despite these limitations, the study is strengthened by a unilateral patient population with contralateral internal controls, standardized imaging acquisition, and excellent interobserver reliability[23].

In conclusion, dynamic MVI performed during mechanical provocation appears to provide additional clinically meaningful information in the ultrasound evaluation of lateral epicondylitis and may improve detection of symptom-related tendon microvascular changes beyond static assessment alone.

Dynamic MVI performed during mechanical provocation provides additional clinically relevant diagnostic information beyond conventional static ultrasound assessment in patients with lateral epicondylitis. While gray-scale ultrasound and static Doppler techniques remain useful for identifying structural tendon abnormalities and baseline vascularity, dynamic evaluation during mechanical provocation enables improved visualization of symptom-related microvascular responses, particularly when advanced MVI techniques are applied.

The observed association between increased provocation-related intratendinous vascularity and higher pain intensity and functional impairment, as reflected by VAS and PRTEE scores, suggests that dynamic microvascular changes may be more closely related to clinical symptom severity than static imaging findings alone.

Incorporation of dynamic microvascular assessment into routine musculoskeletal ultrasound protocols may therefore enhance diagnostic confidence, facilitate detection of clinically relevant tendon pathology, and provide complementary insight into symptom burden in patients with lateral epicondylitis.

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