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Diagnostic Accuracy of Ultrasound Elastography in Meniscus Assessment: A Comparative Analysis with Magnetic Resonance Imaging

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Abstract

Objective: Ultrasonography (US) is a non-invasive, non-ionizing radiation modality which is highly successful at diagnosing meniscal pathologies. The aim of this study is to demonstrate the contribution of strain elastography (SE) to diagnosis by comparing SE and B-mode US findings of the meniscus with magnetic resonance imaging (MRI).

Methods: A total of 22 patients (a total of 30 knees) who presented to the department of sports medicine with knee pain were included the study. All menisci of the 33 knees were evaluated by B-Mode US, SE, and MRI. The result of US, SE and MRI were compared each other. Pearson and Spearman correlation tests were used to evaluate the inter-technique correlation.

Results: The US and MRI findings of medial meniscus anterior horn (MMAH), medial meniscus posterior horn (MMPH), lateral meniscus anterior horn(LMAH), lateral meniscus posterior horn(LMPH) were correlated ($P < .001$, $P < .001$, $P = .002$, $P = .006$). For the evaluation of MMAH and LMPH, the sensitivity of US was 100%, and the specificity was 87% and 80%, respectively. There was a negative correlation between strain ratio (SR) and both of US and MRI injury grades for MMAH, MMPH, and LMPH ($r = -0.389$ and $r = -0.499$ for MMAH; $r = -0.045$ and $r = -0.441$ for MMPH; $r = -0.307$ and $r = -0.691$ for LMPH, respectively). There was a negative correlation between SR and US injury grade for LMAH ($r = -0.341$). The SE elastogram and MRI findings were consistent for only MMAH ($P = .044$).

Conclusion: Ultrasound elastography (USE) is an appropriate and valuable imaging technique that supports MRI and B-Mode US for the detection of meniscal injury.

Keywords: Meniscus, ultrasonography, strain elastography, Magnetic Resonance Imaging

Introduction

The meniscus is a fibrocartilaginous structure located between the tibia and femur.[1] It reduces the load on cartilage by expanding the joint surface. Meniscal degeneration and tears are one of the common causes of knee pain.[2] Correct diagnosis of meniscal injury is important for an appropriate treatment plan. History taking and physical examination can give an idea about the condition of the meniscus. However, imaging modalities are required for diagnosis.[3]

Arthroscopy is the gold standard diagnostic technique for evaluating meniscal pathologies and allows for simultaneous diagnosis and treatment of an injury. The disadvantages of arthroscopy are its invasiveness along with the technical difficulties in use. It is therefore not preferred for diagnostic purposes in the first foreground.[4] The gold standard noninvasive imaging technique for meniscal pathologies is magnetic resonance imaging (MRI) with high sensitivity and specificity.[5] It has the advantages of providing multiplanar imaging and high soft-tissue resolution. However, it is an expensive and relatively difficult examination. Its use is contraindicated for patients with claustrophobia, cardiac pacemaker and metallic implants.[5,6] Ultrasonography (US) is an alternative imaging technique to MRI for the evaluation of meniscus. It can provide some information about meniscal pathologies as well as tendons, ligaments, muscles, synovium, cartilages, and surrounding soft tissues of the knee. The advantages of US are its inexpensiveness, ease of access, and reproducibility. It allows for comparison with the opposite extremity and dynamic examination at the same time.[6]

Ultrasound elastography (USE) is a US-based imaging technique that demonstrates tissue deformation. The periodic pressure is applied to the target tissue with a probe, regularly. The stiffness of tissue can be evaluated qualitatively and quantitatively according to the flexion response. In this way, color scale and strain ratio (SR) values of healthy or pathological tissue are calculated.[7] It is commonly used for the evaluation of parenchymal organ pathologies such as breast and thyroid.[8,9] Recently, it has been used for musculoskeletal injuries (tendon, ligament, cartilage, meniscus) and has been shown to contribute to the diagnosis.[10-12] This study aimed to evaluate the contribution of strain elastography (SE) to diagnosis by comparing SE and B-mode US findings of the meniscus with MRI.

Methods

This clinical study was approved by the Ethics Committee of Kocaeli University (Approval no: 313, Date: July 27, 2018) and was

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conducted in accordance with the principles of the Declaration of Helsinki. An informed consent was obtained from each participant.

Patient Selection

This is a retrospective study conducted from January 2018 to May 2018. The study included patients who presented to the department of sports medicine with knee pain and for whom knee MRI was ordered. Patients with rheumatologic disease, previous knee surgery, smoking and alcohol use were excluded from the study. Patients' body mass index (BMI) was calculated by measuring their body weight and height.

Ultrasound Examination

All US examinations were performed by an experienced radiologist (5 years of experience) who was blinded to MRI findings of patients using a Toshiba Aplio 500 device (Toshiba Medical Systems Corporation, Tokyo, Japan) with a 12 MHz linear transducer. Ultrasonography was performed within a week after the MRI scan. The patient was placed on a stretcher in the supine position. The knee was posteriorly supported with the knee in about 30° of semiflexion. The probe was vertically placed in the anteromedial and anterolateral aspect of the knee joint. The medial meniscus anterior horn (MMAH) and lateral meniscus anterior horn (LMAH) were evaluated in the coronal plane. The patient was then placed in the prone position. The anterior part of the ankle was supported with the knee in 30° of semiflexion. The linear probe was vertically placed in the posteromedial and posterolateral aspect of the knee joint. The medial meniscus posterior horn (MMPH) and lateral meniscus posterior horn (LMPH) were evaluated in the coronal plane.

On, B-mode US, the meniscus was considered as grade 0 if it was fully hyperechoic, grade 1 if there was diffuse hypoechogenicity, grade 2 if heterogeneity or partial tear was present, and grade 3 if a full-thickness or complex tear was present (Figure 1). Subsequently, an examination was performed using the SE technique. Elastograms of examined anatomical structures were evaluated and SR values were measured. On elastogram, the blue color represented the hardest tissue, while the red color represented the softest tissue. The tissue was evaluated as type 1 if the whole structure was blue, type 2 if it was blue-green, type 3 if it was green, and type 4 if the accompanying yellow or red structure was present, at USE (Figure 2).

Magnetic Resonance Imaging Examination

Magnetic resonance imaging findings were retrospectively evaluated by an experienced radiologist who was blinded to the US findings. Knee imaging was performed using the same 1.5 Tesla (Intera Master, Philips Medical Systems, USA) MRI device with an extremity coil. T1WI and T2WI sagittal, fat-suppressed PD axial, and fat-suppressed T2WI coronal slices were acquired.

On MRI, the meniscus were considered as grade 0 if it was completely hypointense, grade 1 if a slight signal increase was present (Figure 3), grade 2 if a partial tear was present (Figure 4), grade 3 if a full-thickness or complex tear was present, on MRI.[13]

Statistical Analysis

Statistical analysis was done using the Statistical Package for Social Sciences version 20.0 software (IBM Corp.; Armonk, NY, USA) software package. Considering MRI examination as the gold standard, positive predictive value, negative predictive value, sensitivity, specificity, and precision were calculated. Pearson and Spearman correlation tests were used to evaluate the inter-technique correlation. A *P*-value less than .05 was considered statistically significant.

Results

30 knees of a total of 22 patients (5 female and 17 male) with a mean age of 23 years (minimum: 19 years, maximum: 50 years) were included in the study. During US examination, 3 patients were excluded from the study because of a history of knee surgery.

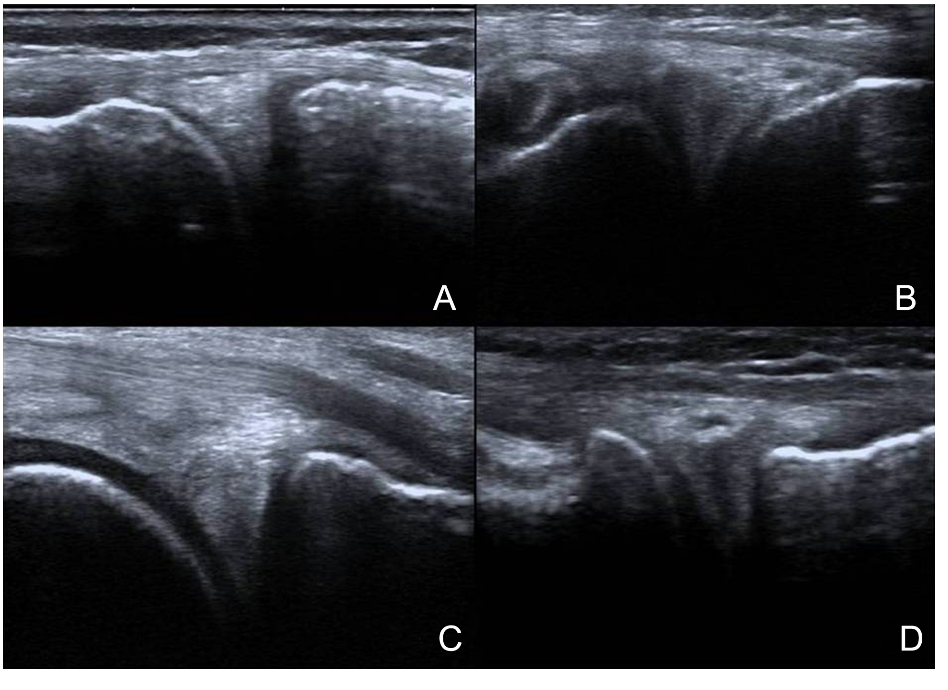

Figure 1. Grades of meniscus on B-Mode Ultrasonography: A. Grade 0: It is fully hyperechoic. B. Grade 1: There is hypoechogenic area. C. Grade 2: Transverse partial tear is present with heterogeneity. D. Grade 3: Transverse and vertical tears (complex tear) are present.

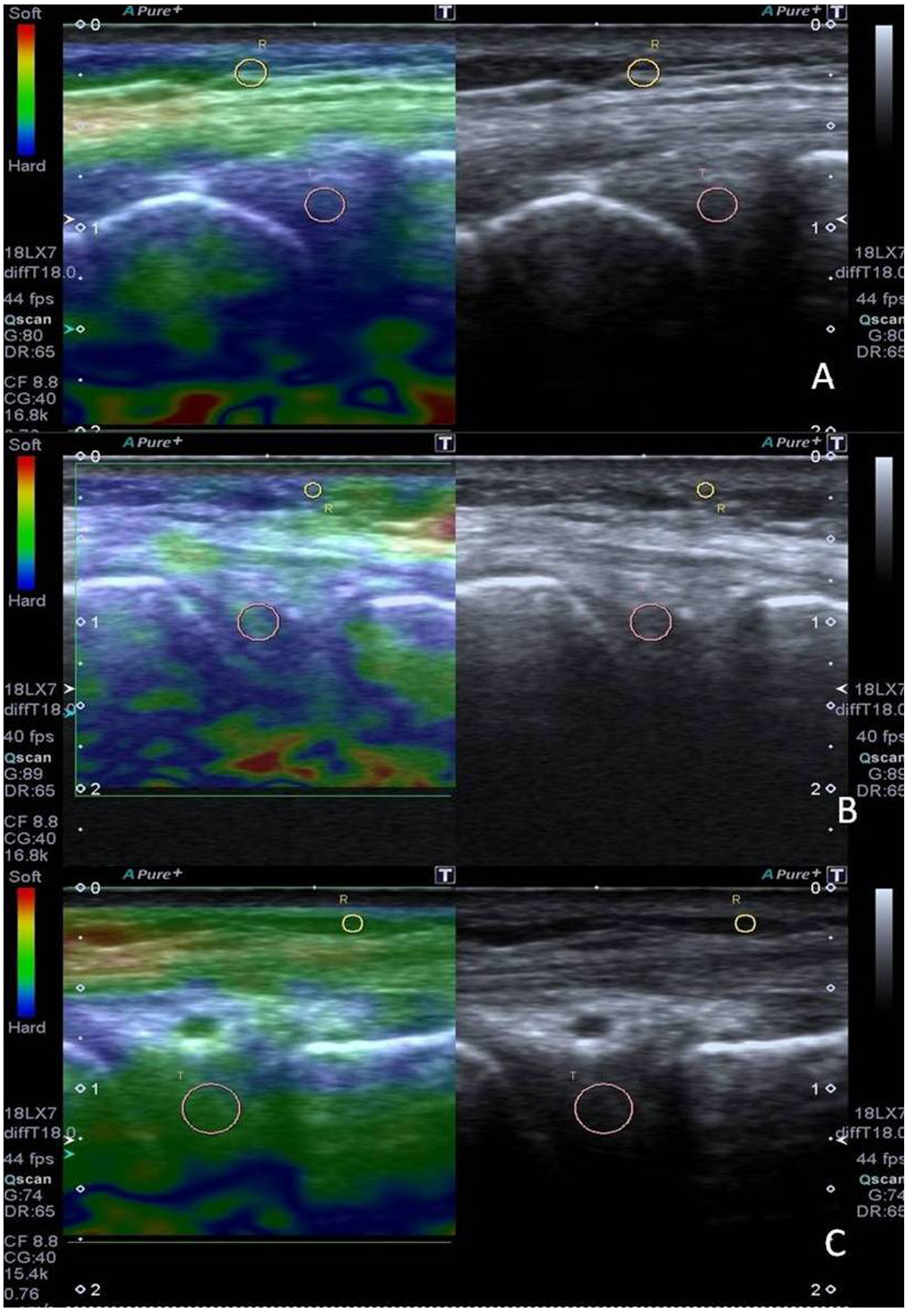

Figure 2. Elastogram patterns of meniscus on ultrasound elastography. A. Type 1: Totally blue color pattern, B. Type 2: Blue-green color pattern, C. Type 3: Totally green color pattern.

Both knees of 8 patients, only the left knee of 7 patients, and only the right knee of 7 patients were examined. The mean BMI of the patients was 25 kg/m^2 (minimum: 19 kg/m^2, maximum: 36 kg/m^2). Of the patients, 81% were actively engaged in sports (for a mean duration of 164 months; minimum: 24, maximum: 336). The mean duration of knee pain complaint was 5 months (minimum: 1, maximum: 12).

The distribution of US and MRI injury grades of the anterior and posterior horns of the lateral and medial menisci is presented in Table 1. The *P* and *r* values revealed by the correlation analysis of B-mode US, USE, and MRI findings are shown in Table 2.

There was a negative correlation between SR and both of US and MRI injury grades for MMAH, MMPH, and LMPH ($r = -0.389$ and $r = -0.499$ for MMAH; $r = -0.045$ and $r = -0.441$ for MMPH; $r = -0.307$; and $r = -0.691$ for LMPH, respectively).

While there was a negative correlation between SR and US injury grade for LMAH ($r = -0.341$), there was a statistically insignificant positive correlation between SR and MRI meniscal injury grade ($P = .647$, $r = 0.087$).

The sensitivity, specificity, diagnostic accuracy, negative predictive value (NPV), and positive predictive value (PPV) of B-Mode US are shown in Table 3.

Discussion

The knee is one of the important weight-bearing joints in the human body with a complex anatomical structure.[14] The meniscus

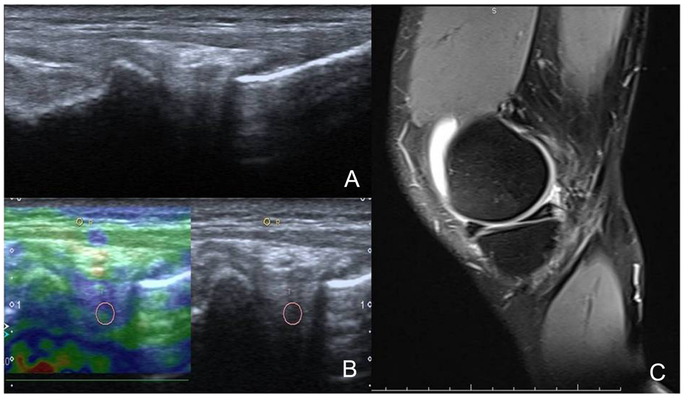

Figure 3. A 47-year-old man's medial meniscus posterior horn images on ultrasonography, ultrasound elastography, and magnetic resonance imaging: There are grade 1 injury on B-mode ultrasonography (A), abnormal color signs (blue-green, type 2 pattern) on ultrasound elastography (B), and grade 1 injury on sagittal PD magnetic resonance imaging (C).

is the most commonly injured structure of the knee. Correct diagnosis of the injury affects the treatment plan.[3] Although arthroscopy is the gold standard diagnostic technique for evaluating meniscus, it is an invasive technique. MRI is the best noninvasive imaging modality alternative to arthroscopy.[15] Chang et al.[16] reported the sensitivity and specificity of MRI for the evaluation of meniscal tears as 92% and 87%, respectively.

The meta-analysis of Dong et al.[17] comparing US and arthroscopy findings of the meniscus found the sensitivity and specificity of US as 89% and 85%, respectively. Cook et al.[18] preoperatively compared the US and MRI findings of the meniscus using arthroscopy. They found that the specificity of US (84%) was higher than that of MRI (67%), while the sensitivity of both techniques was similar. In our study, the US and MRI findings of MMAH, MMPH, LMAH, LMPH were correlated ($P < .001$, $P < .001$, $P = .002$, and $P = .006$, respectively). For the evaluation of MMAH and LMPH, the sensitivity of US was 100%, and the specificity was 87% and 80%, respectively. The SE elastogram and MRI findings were consistent for only MMAH ($P = .044$). The pressure scale was related to the practitioner. There was no numeric parameter that showed the level of the compression–decompression stress. We experienced difficulties in the elastographic evaluation of posterior horns because of anatomy. The surface area of the anteromedial

Table 1. Patient Distribution of Meniscus Damage at Magnetic Resonance Imaging and B-mode Ultrasonography

	MRI	B-Mode US
MMAH		
Grade 0	24	20
Grade 1	1	3
Grade 2	5	7
Grade 3	–	–
MMPH		
Grade 0	4	12
Grade 1	12	6
Grade 2	9	9
Grade 3	5	3
LMAH		
Grade 0	22	18
Grade 1	6	7
Grade 2	2	5
Grade 3	–	–
LMPH		
Grade 0	25	20
Grade 1	4	4
Grade 2	–	6
Grade 3	1	–

B-Mode US, B-mode ultrasonography; MRI, magnetic resonance imaging;

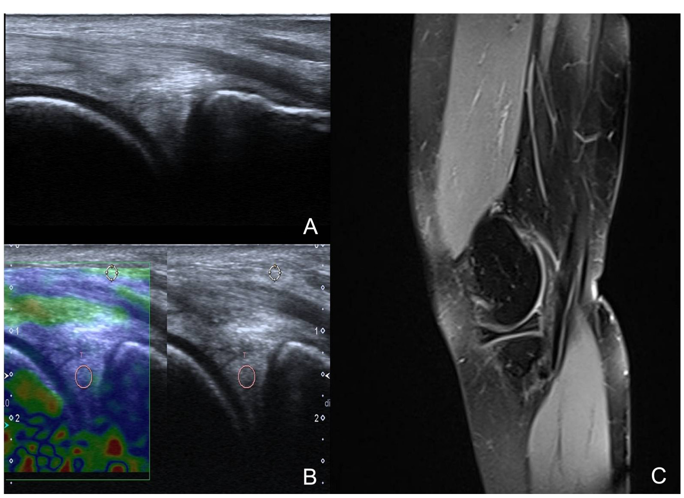

Figure 4. A 36-year-old woman's medial meniscus posterior horn images on ultrasonography, ultrasound elastography, and magnetic resonance imaging: There are grade 2 injury on B-mode ultrasonography (A), abnormal color signs (blue-green, type 2 pattern) on ultrasound elastography (B), and grade 2 injury on sagittal PD magnetic resonance imaging (C).

Table 2. Magnetic Resonance Imaging as Gold Standard Test: ***P*-Values** of B-Mode Ultrasonography vs. Ultrasound Elastography

MRI	B-Mode US, *P* (*r*)	Elastogram, *P* (*r*)
MMAH	**.000** (0.723)	**.044** (0.371)
MMPH	**.000** (0.71)	.252 (0.216)
LMAH	**.002** (0.539)	.368 (0.17)
LMPH	**.006** (0.489)	.078 (0.327)

Values in bold indicate statistical significance ($P < .05$).
B-Mode US, B-mode ultrasonography; LMAH, lateral meniscus anterior horn, LMPH, lateral meniscus posterior horn; MMAH, medial meniscus anterior horn; MMPH, medial meniscus posterior horn; MRI, magnetic resonance imaging.

Table 3. Magnetic Resonance Imaging as Gold Standard Test: Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, and Diagnostic Accuracy of Ultrasonography

Meniscus	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV% (95% CI)	Accuracy % (95% CI)
MMAH	100 (59.04-100)	87 (66.41-97.22)	70 (44.82-87.02)	100	90 (73.47-97.89)
MMPH	65 (44.33-82.79)	75 (19.41-99.37)	94 (75.27-98.96)	25 (13.32-41.96)	67 (47.19-82.71)
LMAH	89 (51.75-99.72)	76 (52.83-91.78)	61(41.84-78.06)	94 (71.29-99.04)	80 (61.43-92.29)
LMPH	100 (47.82-100)	80 (59.30-93.17)	50(31.35-68.65)	100	83 (65.28-94.36)

MRI, magnetic resonance imaging; NPV, negative predictive value; PPV, positive predictive value; US, ultrasonography.

part of the knee was flatter and wider than the posterior. During the examination of MMAH, the practitioner's wrist was supported by the patella. The stabilization of the probe during compressio n–decompression was easier for MMAH. Therefore, it was thought that this result may be partly due to the operator-dependent SE technique of USE.

Bedewi et al.[12] evaluated bilateral MMAH in 34 healthy knee joints using the shear wave elastography (SWE) technique. They found an inverse correlation between the elasticity of the right medial meniscus and the height of the patients, a positive correlation between left MMAH elasticity and BMI, and an inverse correlation between left LMAH elasticity and age. Young et al.[19] evaluated the lateral and medial meniscus of 13 patients with SWE and compared the results with histopathological findings. The histological analysis of the menisci revealed that the stiffness values of the tissue increased as the degeneration increased. Gurun et al.[20] evaluated both knees of 50 patients with SWE and MRI, and in contrast to the results of Bedewi et al.,[12] they found that the stiffness of the meniscus increased as age increased. They also found a positive correlation between the degree of meniscal degeneration on MRI and the stiffness of the meniscus measured with SWE.

In studies evaluating the Achilles tendon with SE, the pathological Achilles tendon has been found to be softer than the healthy tendon.[21] Hsiao et al.[22] found that the patellar tendon of individuals over the age of 60 years were softer than that of younger individuals on USE. Seo et al.[23] compared SE elastogram findings with MRI and US findings in supraspinatus tendinopathy and found a correlation between SE elastogram findings and MRI and US findings of the tendon, and identified tissue softening as tendon injury increased. Knee meniscus tissue is mainly composed of water (90%). The collagen (22%) and glycosaminoglycan (0.8%) are comprised of the non-water component. The collagen content is mostly type 1 (90%). Decreased water and increased proteoglycan content are the results of degenerative meniscus. Minor tears of the interstitial tissue and mucoid degeneration cause damage to collagen fibrils.[24-25] The studies were performed mainly on tendons and muscles.[10,21,22] It was thought that there may be softening in the injured meniscus tissue similar to tendon injuries and that the softening of the injured tissue can be detected by a color change on elastogram and a decrease in SR values. In our study, tissue softening and a decrease in SR values were observed as the degree of meniscal injury increased. There was a negative correlation between SR and both of US and MRI injury grades for MMAH, MMPH, and LMPH.

Symptomatic meniscus injuries affect significantly the daily living of patients. Degenerative changes in the tissue cause volume loss in the long term. Nonfunctional menisci increase the load on the articular surface of the knee. As a result, articular cartilage is lost progressively and the development of osteoarthritis accelerates.[24,25] It is possible to obtain an accurate diagnosis with detailed anamnesis, physical examination, and radiological imaging methods in knee pathologies.[24] Meniscus softening, which is not yet reflected in B-mode US and MRI, can be diagnosed with elastography earlier. Early diagnosis provides to choice of non-surgical management to protect the meniscus health. In this way, the patient can avoid expensive and invasive surgical decisions.

The limitations of our study are the small sample size, the absence of a control group, the use of the SE technique, and not making a comparison with arthroscopic and histopathological findings.

Conclusion

Ultrasound elastography is an appropriate and valuable imaging technique that supports MRI and US for the detection of meniscal injury. It gives an idea about the degree of meniscal injury. However, there is a need for further studies to reach a consensus on the quantitative values of the stiffness of the injured meniscal tissue.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Kocaeli University (Approval no: 313, Date: July 27, 2018).

Informed Consent: An informed consent was obtained from each participant.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.K.B., N.V.; Design – A.K.B., N.V.; Supervision – N.V., T.Ö.; Resources – A.K.B., B.F.; Materials – A.K.B., N.V., B.F.; Data Collection and/or Processing – A.K.B., B.F.; Analysis and/or Interpretation – N.V., T.Ö.; Literature Search – A.K.B., B.F.; Writing Manuscript – A.K.B.; Critical Review N.V., B.F.; Other – B.F., T.Ö.

Declaration of Interests: The authors have no conflict of interest to declare.

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