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A novel semi-quantitative ultrasound scoring method derived from WORMS for assessing cartilage damage in knee osteoarthritis: a cross-sectional study

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Abstract

Background Knee osteoarthritis (KOA) is a chronic degenerative disease characterised by cartilage degeneration subchondral bone hyperplasia. The Whole-Organ MRI Scoring Method (WORMS) evaluates KOA severity through MRI, which can evaluate the pathological changes of the disease. This study introduced the WORMS scoring method for imaging diagnosis and used high-frequency ultrasound (HFUS) to score 14 different areas of the knee joint to semi-quantitatively evaluate cartilage damage in patients with KOA. **Methods** 122 patients diagnosed with KOA at the Gansu Provincial Hospital of Traditional Chinese Medicine between April 2023 and May 2024 were selected. The sub-regions of the knee cartilage were scored using the ultrasound zone double scoring method, and the correlation between these scores and ultrasound grading was analysed. There were 11 cases of grade 0 cartilage injury, 42 grade I, 34 grade II, 18 grade III, and 17 grade IV. The receiver operating characteristic curve (ROC) analysis and the area under the curve (AUC) were used to explore the diagnostic and predictive value of the ultrasound zone score for advanced cartilage damage, and to determine the cut-off value. **Results** Among the 122 patients, 17 patients with cartilage injury grade III-IV underwent knee replacement surgery. The overall agreement

between ultrasound and surgical scores was moderate (weighted kappa = 0.62, 95% CI 0.52–0.72). The total scores of the double-scoring method among the 0-IV grades were statistically significant ($P < 0.05$). The ROC curve indicated that the ultrasound zonation score effectively predicts late KOA injury (AUC 0.964, 95% CI 0.930–0.998), achieving 94.30% sensitivity and 90.80% specificity. **Conclusion** The ultrasound zonal double-scoring method semi-quantitatively evaluates cartilage damage in patients with KOA. However, its diagnostic accuracy remains to be established against an independent reference standard, prospective randomized controlled trials with a large sample size should be conducted to further confirm our study.

Keywords: Knee osteoarthritis, high-frequency ultrasound, cartilage injury, double scoring semi-quantitative

1. Introduction

Osteoarthritis (OA) is a chronic disease that affects the joints and their tissues, resulting in progressive damage to the articular cartilage, followed by damage to the subchondral bone and surrounding synovial structures[1]. Knee involvement is common in patients with OA. Knee osteoarthritis (KOA) is a chronic degenerative disease characterised by degeneration and destruction of knee cartilage and hyperplasia of the subchondral bone. KOA occurs mostly in middle-aged and older adults, and its prevalence is as high as 40% in people aged 70–74 years. With the aging population, patients with KOA are gradually increasing[2, 3]. Although pharmacologic and nonpharmacologic interventions are generally effective at alleviating pain and improving physical function, they do not fundamentally reverse the pathologic and

radiographic process of KOA[4]. Evaluating the degree of cartilage damage in patients can clarify the severity of the disease and provide a reference for formulating subsequent treatment plans.

The main clinical examination methods for diagnosing KOA include X-ray imaging [5], magnetic resonance imaging (MRI) [6], and ultrasound[7]. However, X-ray imaging focuses only on bone and joint space lesions and cannot detect soft tissues, especially cartilage, and X-rays are not sensitive enough for the detection of early knee lesions[8]. However, Arthroscopy has limited clinical application because of its invasive nature (only for diagnosis during surgical treatment)[9]. MRI is a highly accurate imaging method for the evaluation of early pathological changes in the knee joint, and it has high sensitivity and specificity in the examination of cartilage, osteophytes, meniscus changes, synovitis, joint effusion, subarticular bone abnormalities, bursitis, and periarticular soft tissue cysts. However, its high cost and long scanning time limit its application in KOA screening[10]. As a non-invasive examination, high-frequency ultrasound (HFUS) is simple and economical and can diagnose lesions of the articular cartilage, periarticular synovial capsule, tendon, and ligament. Currently, it is widely used for clinical diagnosis of joint diseases[11].

As a scale to assess the severity of KOA by MRI examination, the Whole-Organ MRI Scoring Method (WORMS) can be used to evaluate pathological changes in the disease[12]. In view of this, this study attempts to refer to the WORMS scoring method, and two experienced ultrasound examination doctors use HFUS to score 14 different areas of the knee joint. In order to conduct semi-quantitative evaluation of cartilage

damage in patients with KOA, with the aim of providing convenient and cost-effective quantitative basis for clinical diagnosis and treatment.

2. Materials and Methods

2.1.1. Subjects

Patients diagnosed with KOA at the Gansu Provincial Hospital of Traditional Chinese Medicine between April 2023 and May 2024 were selected and screened strictly according to the inclusion and exclusion criteria. Finally, a total of 122 patients with KOA were included, comprising 31 males and 91 females, with an average age of 57.32±10.32 years. This study was approved by the Ethics Committee of the Gansu Provincial Hospital of Traditional Chinese Medicine, and all subjects provided written informed consent (ethical approval number: 2023-006-01).

The inclusion criteria were as follows: (1) Patients meeting the diagnostic criteria for primary KOA in the 2018 Guidelines for the Diagnosis and Treatment of Osteoarthritis issued by the Orthopaedic Society of Chinese Medical Association[13]. (2) All patients had complete clinical data and underwent musculoskeletal ultrasound examination.

Exclusion criteria: (1) patients had acute traumatic osteochondral injury. (2) Local surgery or traumatic scarring of knee joints. (3) The patient's joint could not be flexed and had severe joint deformity. (4) The patient suffered from a mental illness and was unable to cooperate with the study.

2.1.2 Ultrasound examination methods

A Canon ultrasound diagnostic instrument with a probe frequency of L18 to 12A MHz linear array probe was used, all images were acquired at a standardized depth of 4 cm. During the examination, the knee joint was in full flexion (90° -135°) and the femoral trochlear cartilage was exposed. The medial and lateral femoral and tibial intercondylar cartilages were measured by transverse and longitudinal scans of the lower edge of the patella and popliteal fossa, The scoring criteria were based on WORMS. Two doctors, each with over five years of experience in musculoskeletal ultrasound diagnosis, independently assigned scores to each subregion according to the scoring standard and then calculated the total score. Two readers were blinded to clinical data and to the surgical result, disagreements were resolved by discussion only for the purpose of the final consensus score, but the independent scores were retained for reliability analysis.

Grading criteria for cartilage damage were as follows: Grade 0: normal, the upper boundary of hypoechoic cartilage was a smooth curve, smooth and continuous, clear, and sharp; Grade I: no obvious degeneration, less sharp cartilage surface; Grade II: the surface of degenerative cartilage was rough, local uplift, or slight thinning; Grade III: local thinning of degenerative cartilage; Grade IV: the degenerative cartilage layer was completely absent, and the hypoechoic vocal cords disappeared.

The WORMS was used to assess 14 different areas (Fig.1). The knee was flexed at 90°-135° to allow for better visualisation of the cartilage. Each investigator independently determined cartilage damage scores. The patella was divided into the

lateral bevel cartilage (LP) and medial bevel cartilage (MP). The articular surface of the femur is divided into the medial (MF) and lateral (LF) condyles, and the trochlear groove is considered a part of the MF. The MF and LF were divided into three regions:(1) anterior region (a), extending from the anterior superior osteochondral junction to the anterior margin of the anterior horn of the meniscus; (2) Central region (c), extending from the anterior margin of the anterior horn of the meniscus to the attachment of the posterior capsule of the posterior horn of the meniscus; (3) Posterior region (p), extending from the attachment of the posterior horn of the medial tibial plateau (MT) and lateral tibial plateau (LT) were divided into three equal areas: anterior (A), central (C), and posterior (P). Based on these subdivisions, the patellofemoral joint (PFJ) consists of the MP, LP, MFa, and LFa regions, while the medial femorotibial joint (MFTJ) consists of the MFc, MFp, MTa, MTc, and MTp regions. The lateral femorotibial joint (LFTJ) comprises the LFc, LFp, LTa, LTc, and LTp.

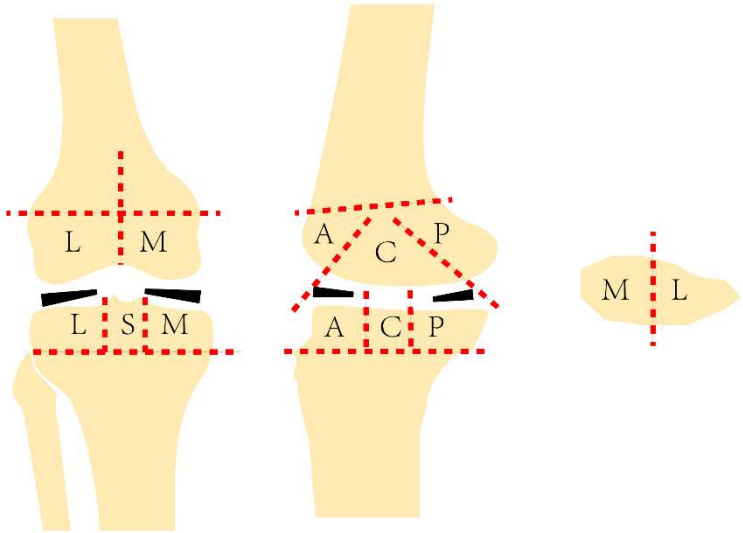


Figure 1 Schematic diagram of WORMS scoring method

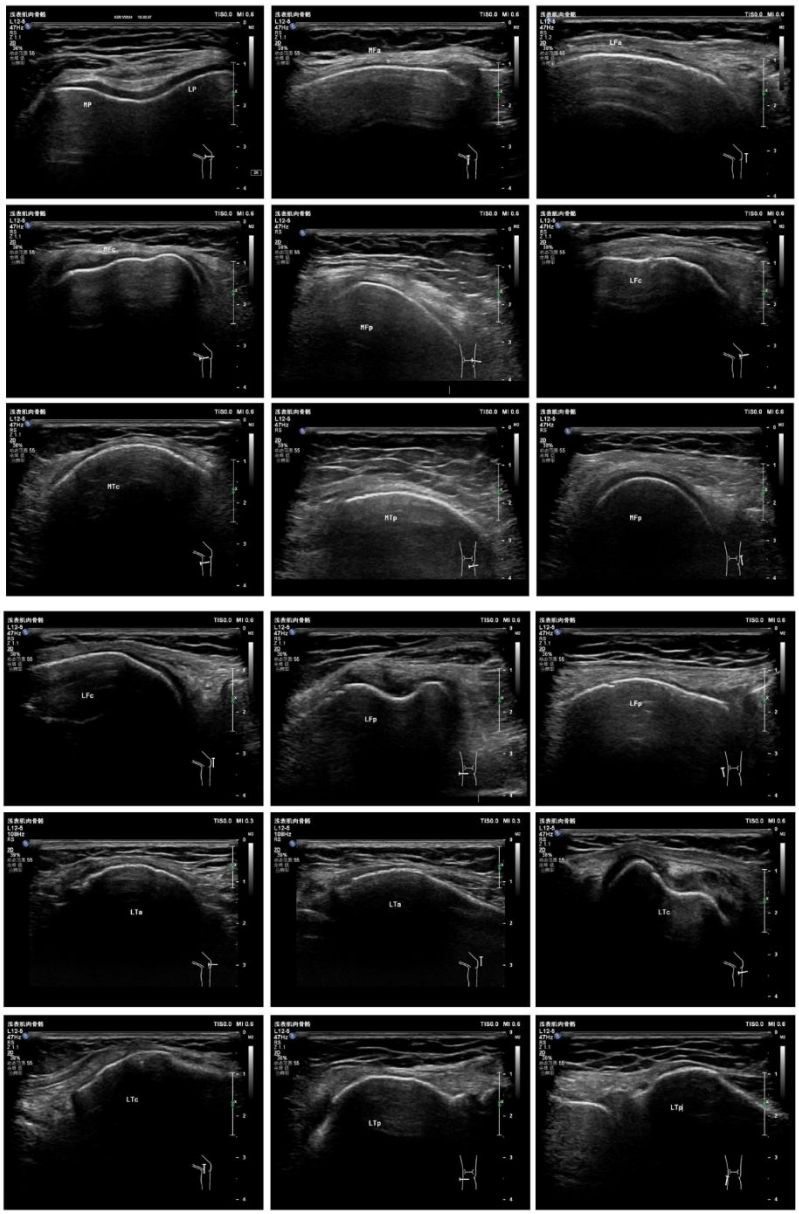


Figure 2 Representative ultrasound images for each cartilage regions

The echo and morphology of the cartilage in 14 articular surface regions were scored. Score 0: normal thickness and echo; 1 point: normal thickness, rough cartilage edge, sound transmission blurred enhancement; 2 points: the maximum width of local cartilage defect < 1 cm; 2.5 points: local cartilage is completely defect and the maximum width is less than 1 cm. 3 points: multiple areas of cartilage defect less than 1 cm or the range of cartilage defect more than 1 cm but the thickness of cartilage defect

less than 2/3 of the normal; Score 4: diffuse (≥75% area) partial cartilage defect; 5 points: multiple full-thickness cartilage defects or multiple defects less than 2/3 thickness relative to normal but more than 1 cm in extent; Score 6: loss of the full thickness of cartilage in more than 75% of the area.

17 patients with grade III-IV cartilage damage underwent knee joint replacement surgery. We also scored the degree of cartilage damage in 14 areas observed during the surgery based on the WORMS scoring criteria.

2.1.3 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 26.0. Quantitative data were described by mean ± standard deviation (x±s) difference or median (M) and interquartile range (QR).For between-group comparisons following one-way ANOVA, post hoc pairwise analyses were performed using Tukey's honestly significant difference (HSD) test. Agreement between ultrasound zonation scores and surgical scores was quantified using quadratic-weighted kappa with 95% confidence intervals. Qualitative data were expressed as n (%), and the chi-square test was used for comparisons between groups. Spearman rank correlation were used to analyse the correlation between two variables. Receiver operating characteristic (ROC) curve analysis and area under the curve (AUC) were used to explore the diagnostic and predictive value of the ultrasound zonation score for late cartilage injury, and the cutoff value was determined. The optimal cutoff was determined using the Youden index, defined as the maximum of (sensitivity + specificity − 1). Statistical significance was set at $P < 0.05$. significant.

3. Results

A total of 122 patients with KOA who met the inclusion and exclusion criteria and, had complete and qualified ultrasound images, were included in this study. The average age of the patients was 57.32±10.32 years. This study included 91 females and 31 males. There were 11 cases of grade 0 cartilage injury, 42 grade I, 34 grade II, 18 grade III, and 17 grade IV. Age comparisons among the five groups were statistically significant ($P < 0.001$), as shown in Table 1.

1.The differences of ultrasound zonation scores and grading in KOA patients

In 122 patients with KOA, the total score obtained by the double-scoring method between each grade of 0-IV was statistically significant ($P < 0.05$), as shown in Table 1.

Table 1 The differences of ultrasound zonation scores and grading in patients with KOA

Ultrasound grading	Cases	Age	Total score
Grade 0	11	48.09±12.09	8.91±4.55
Grade I	42	52.69±8.48	12.05±3.79[a]
Grade II	34	58.09±8.04[a,b]	15.28±3.81[a,b]
Grade III	18	63.67±7.81[a,b,c]	21.78±4.04[a,b,c]

Grade IV	17	66.76±8.71[a,b,c]	31.09±3.31[a,b,c,d]
F value		13.64	95.21
P value		＜0.001	＜0.001

a Compared with grade 0, P < 0.05; b compared with grade I, P < 0.05; c compared with grade II, P < 0.05; d compared with grade III, P < 0.05.

2. The correlation between ultrasound zonation scores with ultrasound grading, sex and age in patients with KOA

Spearman rank correlation analysis was used to test the correlation between ultrasound zonation scores and ultrasound grading as well as sex and age in patients with KOA. The results showed that the ultrasound zonation scores of patients with KOA were positively correlated with age and ultrasound grading (P < 0.05), whereas sex was not correlated with the ultrasound zonation scores of patients with KOA (P > 0.05), as shown in Table 2.

Table 2 The correlation between ultrasound zonation scores with ultrasound grading, sex and age in patients with KOA

	r	P 值
Gender	-0.132	0.148
Age	0.555	＜0.001
Ultrasound grading	0.791	＜0.001

P < 0.05 was considered statistically significant.

3. Comparison of ultrasound scores on different stress surfaces of knee joint inpatients with KOA.

The ultrasound scores of the three different stress surfaces of the knee joint in 122 patients with KOA were compared, and the results showed that the ultrasound scores of the patellofemoral joint (PFJ), medial femorotibial joint (MFTJ), and lateral femorotibial joint (LFTJ) were statistically significant (F=88.986, P < 0.001) (Table 3). In addition, we compared ultrasound scores for cartilage damage on the femoral and tibial force surfaces in patients with KOA. The results showed that the ultrasound scores for cartilage damage on the femoral force surface were higher than those on the tibial force surface in patients with KOA (P=0.018).

Table 3 Comparison of ultrasound scores on different stress surfaces of knee joint inpatients with KOA.

	Mean±SD
PFJ	4.62±2.58
MFTJ	6.43±2.81[a]
LFTJ	5.70±3.00[a,b]
F value	88.99
P value	＜0.001

a Compared to PFJ,P < 0.05; b Compared to MFTJ, P < 0.05.

4. Agreement between ultrasound zonation scores and surgical scores in 17 surgical patients.

17 patients with knee cartilage injury of grade III-IV underwent knee arthroplasty (including 5 patients of grade III and 12 patients of grade IV). Agreement between ultrasound zonation scores and surgical scores was assessed. Agreement was quantified using quadratic-weighted kappa. The overall agreement between the two methods was moderate (weighted kappa = 0.62, 95% CI 0.52–0.72). Agreement varied considerably across subregions (Table 4).

Table 4 Agreement between ultrasound zonation scores and surgical scores in 17 surgical patients

subregion	Ultrasound zonation scores	surgical scores	Weighted kappa (95% CI)	Agreement
LFa	1.79±0.56	1.85±0.52	0.72 (0.42–1.00)	Moderate–substantial
LTa	2.06±0.50	2.15±0.49	0.78 (0.53–1.00)	Substantial
MFa	2.06±0.61	2.12±0.57	0.41 (0.00–0.78)	Fair
MTa	2.12±0.57	1.97±0.67	0.63 (0.31–0.95)	Moderate
LFc	2.29±0.66	2.06±0.66	0.55 (0.22–0.88)	Moderate
LTc	2.85±0.86	2.71±0.81	0.74 (0.47–1.00)	Moderate–substantial
MFc	2.44±0.46	2.74±0.56	0.49 (0.13–0.85)	Fair

MTc	2.97±0.80	2.71±0.75	0.52 (0.17–0.87)	Moderate
LFp	1.71±0.56	1.74±0.50	0.70 (0.41–0.99)	Moderate–substantial
LTp	2.03±0.72	1.88±0.67	0.87(0.68-1.00)	Almost perfect
MFp	2.06±0.43	2.03±0.60	0.61 (0.28–0.94)	Moderate
MTp	1.77±0.53	1.85±0.61	0.68 (0.39–0.97)	Moderate–substantial
LP	1.88±0.57	1.77±0.53	0.66 (0.36–0.96)	Moderate
MP	2.62±0.55	2.71±0.75	0.58 (0.27–0.89)	Moderate
Overall	-	-	0.62 (0.52–0.72)	Moderate

5. The cutoff value of ultrasound zonation score for predicting late cartilage injury in KOA patients

Patients with grades I and II cartilage injury classified by ultrasound were defined as having early cartilage injury, and those with grades III and IV cartilage injury were defined as having late cartilage injury. Using the ultrasound score as the independent variable and late cartilage injury as the outcome variable, an ROC curve was drawn and the AUC was determined. The results showed that the ultrasound zonation score had a high diagnostic efficiency in predicting late cartilage injury (AUC 0.964, 95% CI 0.930–0.998), the best cut-off value for predicting late cartilage injury was 19.25, and the sensitivity and specificity were 94.30% and 90.80%, respectively, as shown in Table 5 and Figure 2.

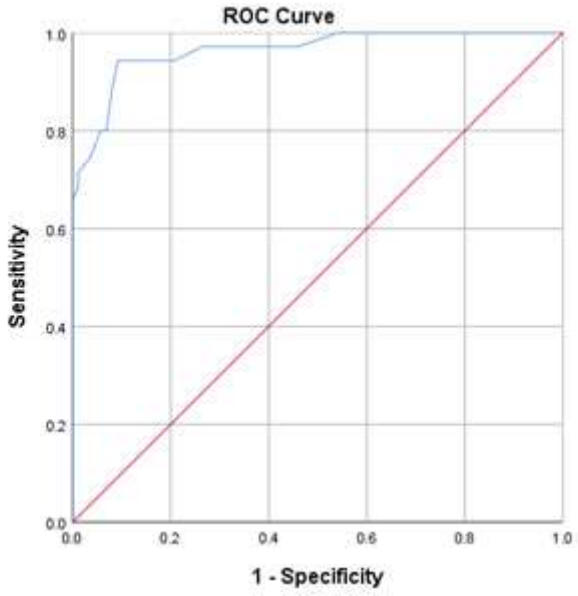


Figure 3 ROC curve of ultrasound zonation score for predicting late cartilage damage in KOA patients

Table 5 ROC curve analysis of ultrasound zonation scores for predicting late cartilage damage in patients with KOA

Variable	AUC	P value	Cut-off	sensitivity（%）	specificity（%）	95%CI
Ultrasound zonation score	0.964	＜0.001	19.25	94.30	90.80	0.930-0.998

4. Discussion

KOA includes a multitude of clinical diseases. Its pathogenesis is scar adhesion after soft tissue injury around the knee joint, leading to long-term contracture and degeneration of soft tissue, which can lead to the loss of physiological function of the knee joint and abnormal biomechanical balance, which has a great impact on the daily

activities and life of patients[14, 15]. Therefore, the accurate diagnosis and evaluation of KOA remain a research hotspot. In recent years, musculoskeletal ultrasonography has been used to diagnose and evaluate bone and joint diseases. It has unique diagnostic value in joint effusion, bone invasion, synovial hyperplasia, blood flow and cartilage damage[16]. Studies have shown that cartilage layer thinning and cartilage reduction can occur in the early stage of patients with KOA. These signs can be detected by ultrasound, and the degree of cartilage degeneration is positively correlated with the course of KOA [17].

In the present study, we assessed agreement between ultrasound zonation scores and surgical scores using quadratic-weighted kappa, rather than relying on non-significant paired tests. This approach was adopted because a non-significant difference test does not demonstrate equivalence or agreement, particularly in a small sample. Our results showed moderate overall agreement between the two methods (weighted kappa = 0.62), with considerable variation across subregions. Several limitations should be acknowledged. The sample size was small, and the confidence intervals for weighted kappa were wide, particularly for subregions with lower agreement. Although Musculoskeletal ultrasound can effectively reflect pathological changes in the articular cartilage and vascular proliferation around the articular surface to improve diagnostic efficiency. However, in clinical practice, musculoskeletal ultrasonography has its own limitations in the diagnosis and evaluation of KOA[18]. Some patients with KOA have severely limited joint flexion, and the joint space disappears or narrows. It is difficult for sound waves to pass through the joint cavity, which affects the presentation of the

femoral head and tibial plateau cartilage. In a flexed knee, ultrasound cannot reliably access the posterior tibial and femoral regions or the central weight-bearing femoral cartilage, which are precisely the regions most affected in osteoarthritis[19]. To a certain extent, the detection and evaluation results are affected by the operator's technology and subjective experience[20, 21].

Many complex factors induce KOA, and biomechanical factors are important in its formation. When the local articular cartilage bears a higher-than-normal level of stress, the cartilage wears and the thickness is uneven, which leads to a decline in joint stability, makes the stress concentration more obvious, and further aggravates the wear of the cartilage[22]. The results of this study showed that the ultrasound scores for cartilage damage in the MFTJ were higher than those in the PFJ and LFTJ. The knee joint is composed of the medial (MFTJ), patellofemoral (PFJ), and lateral (LFTJ) compartments. KOA usually begins with the degeneration of the soft tissue and cartilage of the medial compartment and then progresses to patellofemoral or lateral compartment arthritis. In daily activities, the knee joint bears 2–4 times its own body weight, and nearly two-thirds of this weight is borne by the medial compartment, which is the physiological reason why KOA primarily occurs in the medial compartment[23]. Fukaya et al. [24]found that stress in the medial compartment significantly increased in patients with KOA and severe varus deformity. The internal compliance of the KOA knee joint changes, and the joint becomes unstable. As the medial cartilage wear progresses, the contact pressure and stress of the medial compartment increases. To maintain the internal balance of the joint, the stress of the lateral compartment begins

to increase, which promotes the progression of KOA[25]. This further confirmed the results of the present study.

The results of this study showed that the ultrasound score for cartilage injury on the femoral force surface was higher than that on the tibial force surface in patients with KOA (P=0.018). Souza et al. analysed the MRI images of 137 patients with KOA and healthy people, and the results showed that the T1rho and T2 relaxation times of the tibial cartilage in response to load were consistently reduced in all subjects, indicating that the damage to the femoral cartilage on the force surface was higher than that of the tibial cartilage on the force surface in KOA patients, which was consistent with the results of this study. This may have been related to the biomechanical requirements of the joints. As the knee flexed, the contact point experienced a greater offset on the femoral condyle than on the tibial plateau because of the different shapes of the two articular surfaces[26]. Thus, the raised femur is subjected to both compressive and shear forces, in contrast to the relatively flat tibia, which is subjected to less shear force [27].

In this study, patients with ultrasound grades I and II cartilage injuries were defined as having early cartilage injury, and those with grades III and IV cartilage injuries were defined as having late cartilage injury. Using the ultrasound score as the independent variable and late cartilage injury as the outcome variable, an ROC curve was drawn, and the AUC was determined. The results showed that the ultrasound zoning score had a high diagnostic efficiency in predicting late KOA injury (AUC 0.964, 95%CI 0.930-0.998), the best cutoff value for predicting late KOA injury was 19.25, and the sensitivity and specificity were 94.30% and 90.80%, respectively. These findings raise

the hypothesis that it is necessary to simultaneously evaluate cartilage damage on different stress surfaces in patients with early stage KOA, and clinicians can actively monitor and prevent late cartilage injury in KOA patients to improve their quality of life. However, due to the exploratory nature of this study, we were unable to perform a robust internal or external validation, the cut-off should be regarded as hypothesis-generating and needs validation in prospective, independent cohorts. Atik et al [28]demonstrated the potential of optimized deep learning models for OA severity classification using knee radiographs. In the future, the deep learning method can be further utilized to study the application of musculoskeletal ultrasound in classifying the severity of osteoarthritis in the knee joint. This will provide broader context for the evolving role of imaging techniques in the diagnosis and severity assessment of knee osteoarthritis.

This study has several limitations. First, it was a single-center study, only the clinically indicated knee was examined in each patient, in accordance with the referring physician's order, therefore, bilateral or asymptomatic knees were not evaluated. This may limit the assessment of bilateral or subclinical involvement, thus, selection bias cannot be ruled out. Therefore, multi-center studies are needed to validate our findings. Second, although ultrasound has a high resolution for local soft tissue, it lacks an understanding of the overall mechanics and microscopic and biochemical changes of the knee joint, and there are certain blind areas in ultrasound examination. Third, we did not evaluate participants in the short term (i.e., 1 and 2 years), we intend to perform a short-term follow-up in future studies. Fourth, the relatively small sample size and

lack of a normal control group in this study limited the reliability of the data. In addition, participants with KOA at baseline had higher BMI and age, these factors may influence knee cartilage scores, the pathophysiology of cartilage damage in KOA patients should be carefully evaluated. Therefore, cohort studies with larger sample sizes, especially prospective cohort studies, should be conducted in the future to evaluate the value of the ultrasound zone-double score semi-quantitative method for the diagnosis of knee osteoarthritis cartilage damage.

5. Conclusion

In conclusion, the ultrasound zonal double-scoring method semi-quantitatively evaluates cartilage damage in patients with KOA. However, its diagnostic accuracy remains to be established against an independent reference standard, prospective randomized controlled trials with a large sample size should be conducted to further confirm our study.

Declarations

Ethics approval and consent to participate

All patients agreed to participate in this clinical trial by signing an informed consent form. The study was approved by the Ethics Committee of the Gansu Provincial Hospital of Traditional Chinese Medicine, and was performed in accordance with the ethical standards of the Declaration of Helsinki of 1964.

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Data availability

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

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author contributions

Study Design A: Qun Qiang, Collection B: Lijuan Zhang, Statistical Analysis C: Miaomiao Zhang, Data Interpretation D: Yulan Zheng, Manuscript Preparation E: Lijuan Zhang, Literature Search F: Qian Wang.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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