

## Original Article

# The Diagnostic Value of Musculoskeletal Ultrasound in Knee Osteoarthritis and Its Correlation with Pain Stratification

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**Abstract**

**Objective:** This study aimed to evaluate the diagnostic value of musculoskeletal ultrasound in patients with knee osteoarthritis (KOA) and to assess its correlation with pain stratification, with the goal of supporting early diagnosis and personalized pain management in KOA. **Methods:** A total of 128 patients with KOA were retrospectively selected. Based on their visual analogue scale (VAS) scores, the patients were categorized into mild, moderate, and severe KOA groups. Line charts and histograms were used to illustrate the distribution and variation of pain levels and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores. Scatter plots were generated to analyze the correlation between musculoskeletal ultrasound findings and pain scores. **Results:** Preliminary analysis revealed a significant correlation between ultrasound findings and both VAS and WOMAC scores ( $P < 0.05$ ). Line charts demonstrated an upward trend in VAS scores with increasing pain severity. Histograms indicated significant differences in the distribution of WOMAC scores across different pain stratification levels. **Conclusion:** Musculoskeletal ultrasound demonstrates strong diagnostic value in KOA and shows a significant correlation with pain stratification. This non-invasive imaging modality may serve as an effective clinical tool for individualized pain assessment and informed treatment planning.

**Keywords:** Knee Osteoarthritis, Musculoskeletal Ultrasound, Pain Stratification, Synovial Fluid Volume, Synovial Membrane Thickness

**Introduction**

Knee osteoarthritis (KOA) is a degenerative joint disease that primarily affects middle-aged and elderly individuals, presenting with symptoms such as pain, swelling, and impaired function<sup>1,2</sup>. The global prevalence of KOA is rising steadily, affecting approximately 10% to 15% of adults, with incidence increasing significantly with age<sup>3,4</sup>. Pathological features of KOA typically include progressive cartilage degradation, alterations in subchondral bone architecture,

and chronic synovial inflammation<sup>5-7</sup>. These changes not only impair joint function but also substantially diminish patients' quality of life and contribute to psychological stress and socioeconomic burden<sup>8</sup>.

Currently, treatment options for KOA include pharmacological therapy, physical rehabilitation, and surgical intervention<sup>9,10</sup>. Among these, nonsteroidal anti-inflammatory drugs (NSAIDs) are commonly prescribed to alleviate pain<sup>11,12</sup>; however, prolonged use may lead to gastrointestinal complications and cardiovascular risks. Physical therapy can enhance joint mobility and strength but often requires sustained patient adherence<sup>13</sup>. Surgical procedures, such as total knee arthroplasty, offer symptom relief for advanced cases but are not universally suitable and carry the risk of postoperative complications<sup>14</sup>. Moreover, conventional imaging modalities—such as radiography and magnetic resonance imaging (MRI)—while useful for structural evaluation, have limited sensitivity and specificity for detecting early-stage lesions and subtle pathological changes<sup>15</sup>. These limitations underscore the need for more

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sensitive, accessible, and cost-effective diagnostic tools.

Musculoskeletal ultrasound has emerged as a valuable non-invasive imaging modality capable of real-time, dynamic assessment of joint structures, with high sensitivity and reproducibility<sup>16</sup>. Previous studies have demonstrated that musculoskeletal ultrasound can detect joint effusion, synovial hypertrophy, cartilage degeneration, and even bone marrow lesions<sup>17,18</sup>. Compared to other imaging techniques, ultrasound offers advantages such as portability, lower cost, and greater accessibility, making it a promising tool in routine clinical practice<sup>19</sup>. As such, musculoskeletal ultrasound is expected to play a significant role in the early diagnosis, monitoring, and therapeutic evaluation of KOA.

This study aimed to assess the diagnostic utility of musculoskeletal ultrasound in KOA and to investigate its association with pain stratification. By analyzing the relationship between ultrasound findings and clinical assessments, we seek to establish an evidence-based framework for the early detection and personalized management of KOA, ultimately improving clinical outcomes and quality of life for affected patients.

## Materials and Methods

### *Study Design and Participants*

This study employed a retrospective design and included patients diagnosed with KOA at our hospital between June, 2022 and April, 2024. Based on their visual analogue scale (VAS) pain scores, patients were categorized into three groups: mild KOA (VAS score 0–3, n = 34), moderate KOA (VAS score 4–6, n = 43), and severe KOA (VAS score 7–10, n = 51). Demographic information, WOMAC scores, and musculoskeletal ultrasound findings were collected and analyzed to assess the diagnostic value of ultrasound and its correlation with pain stratification in KOA. All patient data were anonymized to protect privacy and ensure confidentiality.

Inclusion criteria:

- Age  $\geq$  40 years
- Clinical diagnosis of KOA based on the American College of Rheumatology criteria
- Underwent musculoskeletal ultrasound of the knee within the past year
- Provided informed consent for participation
- Complete clinical data available, including VAS and WOMAC scores

Exclusion criteria:

- Recent knee injection (e.g., intra-articular corticosteroids) or surgical intervention
- Severe systemic conditions (e.g., malignancy, advanced cardiopulmonary disease) that could affect study outcomes
- Other causes of knee pain (e.g., rheumatoid arthritis, infection) or factors that may interfere with pain evaluation

- Inability to complete the assessment questionnaires or undergo ultrasound examination

### *Ultrasound Assessment of Joint Fluid Volume*

Joint fluid volume was measured using a high-resolution musculoskeletal ultrasound system equipped with a linear array transducer operating at 10–18 MHz. Patients were examined in a sitting or supine position with the knee fully exposed. The probe was placed along the midline of the knee to allow comprehensive visualization of intra-articular effusion. The area with the maximum synovial fluid accumulation was identified, and the volume was measured in milliliters (mL) using the ultrasound system. Both knees were assessed, and the greater fluid volume of the two was used for subsequent analysis.

Ultrasound measurements were performed concurrently with clinical assessment and pain scoring, prior to any intra-articular injection or modification of treatment. Synovial membrane thickness was defined as the perpendicular distance from the synovial lining to the joint capsule at the femoral surface. Each measurement was repeated three times, and the mean value was recorded. All assessments were conducted by two experienced musculoskeletal radiologists. In accordance with previous literature, synovial thickness greater than 4 mm was considered indicative of active synovitis<sup>20</sup>. Although all participants underwent standard knee radiography, these data were excluded from the analysis due to the limited sensitivity of X-rays for evaluating soft tissue inflammation.

### *Distribution and Trends of WOMAC and VAS Scores*

The distribution and progression of VAS and WOMAC scores across different KOA severity groups were visualized using line charts and histograms. VAS and WOMAC data for all participants were collected and plotted using statistical software. Line charts were used to illustrate score trends across severity levels, while histograms displayed the frequency distribution of scores within each group.

### *Correlation Between Ultrasound Findings and VAS Scores*

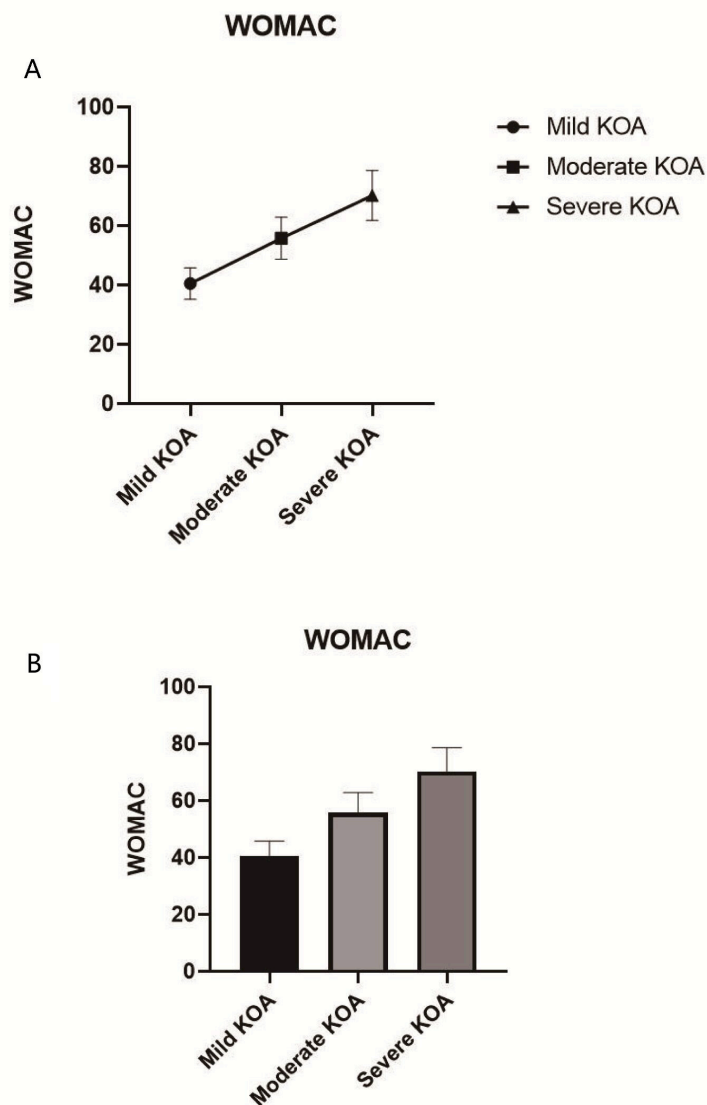
The relationship between musculoskeletal ultrasound findings—specifically synovial membrane thickness—and VAS scores was assessed using scatter plots. Ultrasound measurements were matched with corresponding VAS scores for each patient, and scatter plots were generated to visualize the correlation. Pearson correlation coefficients were calculated to quantify the strength and direction of the association, providing further insight into the diagnostic and prognostic utility of musculoskeletal ultrasound in KOA.

## Statistical Analysis

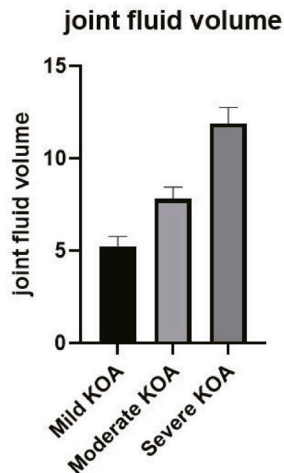
All statistical analyses were performed using IBM SPSS Statistics version 23. Continuous variables were expressed as mean  $\pm$  standard deviation (SD). One-way analysis of

**Table 1.** Baseline characteristics of the study population. KOA: Knee osteoarthritis.

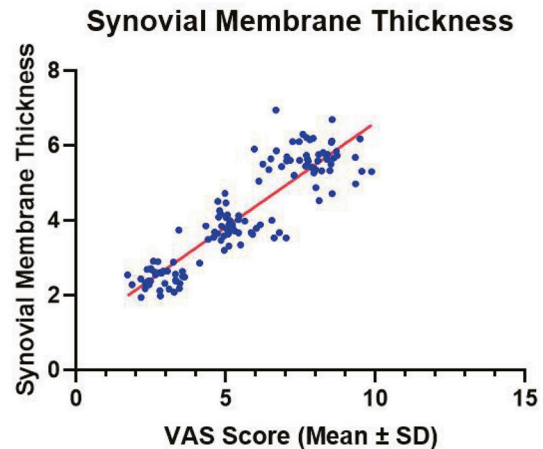
Characteristic	Mild KOA (n=34)	Moderate KOA (n=43)	Severe KOA (n=51)	F	P-value
Age (years)	51.8 ± 5.2	52.4 ± 5.2	51.9 ± 5.5	0.161	0.387
Male (%)	40	35	30	0.621	0.539
BMI (kg/m <sup>2</sup> )	24.8 ± 2.2	24.9 ± 2.3	24.85 ± 2.25	0.019	0.981
Disease Duration (years)	4.1 ± 1.25	4.05 ± 1.3	4.15 ± 1.2	0.075	0.928
VAS Score (Mean ± SD)	2.8 ± 0.5	5.2 ± 0.7	7.9 ± 0.9	489.532	P<0.001



**Figure 1.** Distribution and changes of WOMAC scores. A. WOMAC line chart of different KOA patients. This figure shows the trends in WOMAC scores in patients with mild, moderate, and severe KOA. The line chart shows that as the severity of KOA increases, the WOMAC score increases significantly. The WOMAC score of the mild KOA group was  $40.5 \pm 5.3$ , the moderate KOA group was  $55.8 \pm 7.1$ , and the severe KOA group was  $70.2 \pm 8.4$  ( $P < 0.05$ ). B. WOMAC histograms of different KOA patients. This figure shows the distribution of WOMAC scores in patients with mild, moderate, and severe KOA. The histogram shows that the WOMAC score increases significantly with increasing KOA severity.



**Figure 2.** Joint fluid volume in different KOA patients. This figure shows joint fluid volumes in patients with mild, moderate, and severe KOA. The histogram shows that the joint fluid volume increases significantly with increasing KOA severity. The average synovial fluid volume was  $5.22 \pm 0.55$  mL in the mild KOA group,  $7.80 \pm 0.64$  mL in the moderate group, and  $11.88 \pm 0.87$  mL in the severe group ( $P < 0.05$ ).



**Figure 3.** Scatter plot of correlation between synovial thickness and VAS score. This figure shows the correlation between synovial thickness and VAS score. The scatter plot showed that there was a significant positive correlation between synovial thickness and VAS score (Pearson correlation coefficient = 0.9,  $P < 0.05$ ). As synovial thickness increases, VAS scores increase significantly.

variance (ANOVA) was employed to compare differences among the KOA severity groups. Pearson's correlation coefficient was used to assess the association between synovial membrane thickness and VAS scores. A p-value of  $< 0.05$  was considered statistically significant.

## Results

### Baseline Characteristics

A total of 128 patients with KOA were included in this study, with a mean age of  $52.4 \pm 6.0$  years. Patients were categorized into three groups based on disease severity: mild ( $n = 34$ ), moderate ( $n = 43$ ), and severe ( $n = 51$ ). The mean ages of patients in the mild, moderate, and severe KOA groups were  $50.2 \pm 5.1$ ,  $52.3 \pm 6.2$ , and  $54.8 \pm 5.8$  years, respectively. Approximately 40% of the total cohort were male. The mean body mass index (BMI) values were  $24.5 \pm 2.3$  kg/m<sup>2</sup>,  $25.1 \pm 2.5$  kg/m<sup>2</sup>, and  $26.0 \pm 2.8$  kg/m<sup>2</sup> in the mild, moderate, and severe groups, respectively. The mean disease duration was  $3.2 \pm 1.1$  years for the mild group,  $4.5 \pm 1.3$  years for the moderate group, and  $6.0 \pm 1.5$  years for the severe group. No statistically significant differences were observed among the groups in terms of age, gender distribution, BMI, or disease duration ( $P > 0.05$ ). However, there were statistically significant differences in VAS scores among the three groups ( $P < 0.001$ ) (Table 1).

### Distribution and Trends in WOMAC Scores

WOMAC scores increased significantly with KOA severity. The mean WOMAC score was  $40.5 \pm 5.3$  in the mild group,  $55.8 \pm 7.1$  in the moderate group, and  $70.2 \pm 8.4$  in the severe group ( $P < 0.05$ ), indicating statistically significant differences among all three groups (Figure 1A). Histogram analysis further revealed distinct distribution patterns, with a clear shift toward higher WOMAC scores as KOA severity increased (Figure 1B).

### Ultrasound-Based Analysis of Joint Fluid Volume

Musculoskeletal ultrasound revealed significant differences in synovial fluid volume across the KOA severity groups. The mean synovial fluid volume was  $5.22 \pm 0.55$  mL in the mild group,  $7.80 \pm 0.64$  mL in the moderate group, and  $11.88 \pm 0.87$  mL in the severe group. One-way ANOVA indicated that these differences were statistically significant ( $P < 0.05$ ). A progressive increase in joint fluid volume with disease severity was observed (Figure 2), supporting the utility of ultrasound in evaluating disease progression and pain stratification in KOA.

### Correlation Between Ultrasound Findings and Pain Scores

Synovial membrane thickness also varied significantly with KOA severity. The mean synovial thickness was  $2.45 \pm 0.25$  mm in the mild group,  $3.80 \pm 0.35$  mm in

the moderate group, and  $5.65 \pm 0.45$  mm in the severe group. Scatter plot analysis demonstrated a strong positive correlation between synovial thickness and VAS scores (Figure 3). As synovial thickness increased, corresponding VAS scores also rose. The Pearson correlation coefficient was 0.90 ( $P < 0.05$ ), indicating a strong correlation. These findings suggest that synovial thickness, as measured by ultrasound, is a reliable indicator of pain severity in KOA, reinforcing its value in clinical assessment and stratified patient management.

## Discussion

This study assessed the clinical utility of musculoskeletal ultrasound in the diagnosis of knee osteoarthritis (KOA), with a particular focus on its correlation with pain stratification. The findings demonstrated a significant relationship between ultrasound-derived parameters—namely, joint fluid volume and synovial membrane thickness—and pain severity, as measured by VAS and WOMAC scores. Specifically, both synovial fluid volume and synovial thickness increased in parallel with KOA severity, highlighting the potential of ultrasound to serve as a reliable, non-invasive biomarker for disease assessment and pain evaluation. These insights support the use of musculoskeletal ultrasound in guiding personalized pain management and therapeutic decision-making in KOA patients.

When compared to the existing literature, our results further underscore the advantages of musculoskeletal ultrasound in evaluating inflammatory changes associated with KOA. In contrast to traditional imaging modalities such as X-ray—which are primarily effective for visualizing bony structures—ultrasound is more sensitive in detecting soft tissue abnormalities, including synovitis and joint effusion. Additionally, its real-time, dynamic capabilities allow for more comprehensive assessment of joint inflammation<sup>21–23</sup>. This study quantitatively demonstrated that patients with severe KOA exhibit significantly greater joint effusion and synovial thickening compared to those with milder forms of the disease—findings that strongly correlate with higher pain and functional impairment scores.

An important innovation of this study lies in its quantitative approach to correlating ultrasound metrics with pain stratification. While prior studies have largely been descriptive in nature<sup>24</sup>, our findings contribute to a data-driven framework that may aid clinical decision-making and support the potential integration of ultrasound into routine management of KOA. These findings enhance the diagnostic and prognostic utility of musculoskeletal ultrasound, offering a clinically actionable tool for stratifying patients based on their pain profiles.

Despite these contributions, several limitations should be acknowledged. First, the retrospective design introduces the possibility of selection bias, and the relatively small sample size may limit the generalizability of the findings. Second, the study focused solely on synovial fluid volume and

synovial membrane thickness as ultrasound parameters, without incorporating additional biological markers (e.g., inflammatory cytokines or synovial fluid composition), which could have provided a more comprehensive picture of the disease process. Third, the accuracy of ultrasound measurements may vary depending on operator experience, underscoring the need for standardization and training to minimize interobserver variability.

Future research should aim to validate these findings in larger, prospective cohorts. Incorporating molecular and biochemical biomarkers could enhance the multidimensional assessment of KOA. Additionally, the development and integration of artificial intelligence (AI)-based tools may improve the objectivity, reproducibility, and efficiency of ultrasound evaluations. AI-enhanced ultrasound could further minimize operator dependency and elevate the role of musculoskeletal ultrasound in both clinical and research settings.

## Conclusion

This study demonstrates that musculoskeletal ultrasound is an effective tool for quantifying joint fluid volume and synovial membrane thickness in patients with KOA. These ultrasound parameters significantly correlate with pain stratification and reflect the degree of joint inflammation. The findings support the utility of musculoskeletal ultrasound as a non-invasive, accessible modality that provides a scientific foundation for early diagnosis and individualized management of KOA. Given its diagnostic accuracy and clinical practicality, musculoskeletal ultrasound holds considerable potential for broader integration into routine assessment and treatment planning for KOA.

### Ethics approval

*This study was approved by the Ethics Committee of The First People's Hospital of Jiashan (Approval Number: 2024-Med-091) and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (1964) and its later amendments.*

### Consent to participate

*Written Informed consent was obtained from all individual participants included in the study.*

### Authors' Contributions

*Wenfang Cui: Conceptualization; Methodology; Data curation; Formal analysis; Writing – original draft; Writing – review & editing; Statistical analysis; Supervision. Fuwang Zhang: Conceptualization; Methodology; Project administration; Writing – review & editing; Resources; Visualization. All authors read and approved the final version of the manuscript.*

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