Feasibility and efficacy of ultrasound in the diagnosis of discoid lateral meniscus and its classification in children: protocol for a prospective, multicentre, diagnostic test study

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ABSTRACT
Introduction Although ultrasound can reportedly diagnose discoid lateral meniscus (DLM) in children, its widespread application is challenging because the diagnostic criteria are based on qualitative descriptions of DLM morphology rather than quantitative parameters. Additionally, no studies have applied ultrasound in classifying DLM. Therefore, this study aims to establish the quantitative ultrasound parameters that reflect DLM morphology, evaluate the feasibility and validity of these parameters for identifying DLM and their classification, and develop the quantitative ultrasound diagnostic criteria for DLM and their classification in children.

Methods and analysis Patients will be recruited from the outpatient clinics of the orthopaedics department at West China Hospital, Sichuan University, the Fourth Medical Center of the Chinese People’s Liberation Army General Hospital, Xinhua Hospital affiliated with Shanghai Jiao Tong University School of Medicine, Yibin Hospital affiliated with West China Hospital Sichuan University, Suiyi Central Hospital and the Third Hospital of Mianyang from August 2022 to July 2024. Eligible patients are those aged ≤14 years, with knee symptoms such as pain, locking and limited extension, and who planned to undergo arthroscopic surgery. Exclusion criteria are patients with contraindications to ultrasound examination, such as severe skin damage or fracture around the knee. The sample size is estimated to be 576 cases with a power of 0.9 for hypothesis testing, a two-sided α of 0.05, and an expected sensitivity and specificity of 95%. Three days before surgery, ultrasound will be used to observe the morphology of the lateral meniscus and measure its width, angle formed by the chord of upper and lower arc-shaped articular surface at the free edge, and the movement distance of the peripheral rim. Participants will be categorised according to the arthroscopy results for the DLM and its classification. The diagnostic performance of each parameter will be assessed and compared in terms of the area under the curve, sensitivity, specificity, and positive and negative predictive values.

Ethics and dissemination This study was approved by the Ethics Committee of West China Hospital, Sichuan University (approval no. 2022-923), and this approval covers all study hospitals. Written informed consent is required from all participants before enrolment in the study. The study’s findings will be disseminated through peer-reviewed publications and conference presentations.

STRENGTHS AND LIMITATIONS OF THIS STUDY
⇒ A prospective and multicentre study with a large sample size, aiming to explore the diagnostic feasibility of ultrasound for discoid lateral meniscus (DLM) and its classification in children.
⇒ Aims to classify DLM based on its morphology and peripheral rim stability and to develop quantitative diagnostic criteria for ultrasound in children.
⇒ Potential differences in ultrasound measurements among different ages will not be explored.

INTRODUCTION
Discoid lateral meniscus (DLM) is a congenital disease of the lateral meniscus characterised by an abnormal increase in width, potential instability of the peripheral rim and a disordered arrangement of internal collagen fibres. DLM is categorised according to its morphology and peripheral rim stability (PRS) into complete DLM (CDLM), incomplete DLM (IDLM), DLM with a stable peripheral rim (SPR-DLM) and DLM with an unstable peripheral rim (UPR-DLM), respectively. DLM is common in Asians, with a prevalence of approximately 10.5%–16.6%, with bilateral DLM accounting for 79%–97% of the cases. DLM is prone to tears and degeneration because of its abnormal morphology and tissue structure, including knee pain, locking and other symptoms, particularly in children and adolescents. Considering the aggravation of DLM tears, the articular...
cartilage lesions and knee osteoarthritis ensue, severely affecting the quality of life and causing heavy economic and medical burdens to families and society. Therefore, DLM should be promptly diagnosed, particularly before lesions of the DLM or related intra-articular structures, to substantially improve the long-term clinical efficacy postoperatively.

MRI is considered the gold standard for diagnosing DLM in adults with higher sensitivity and specificity in identifying IDLM and CDLM. Nevertheless, because MRI cannot observe the PRS dynamically, it is challenging to distinguish between the SPR-DLM and UPR-DLM. PRS is pivotal for treatment planning and prognosis prediction. Moreover, MRI is expensive, time-consuming, and unsuitable for children and patients with magnetic metal implants, cardiac pacemakers, or claustrophobia. Particularly, children cannot tolerate the closed and high-noise MRI examination environment, which can lead to motion artefacts and seriously impact the quality of MRI. Furthermore, more than 12% of children still experience motion artefacts after sedation, which may cause severe complications such as cardiopulmonary depression and brain development. Moreover, significant differences exist in the morphology and vascular distribution of DLM between children and adults, which may influence the diagnostic value of MRI for DLM in children. Therefore, the feasibility and efficacy of MRI for DLM diagnosis in children remain controversial, and exploring a new technique to solve this dilemma is necessary.

Ultrasound has the advantages of high soft tissue resolution and real-time dynamic evaluation, which can be used to observe the morphology of the lateral meniscus and evaluate the PRS under extension and different flexion angles of the knee. Additionally, ultrasound is low-cost, convenient, mobile, provides a comfortable examination posture and open examination environment, and can be accompanied by kinship. Compared with adults, the epiphysis in children is not closed, and the cartilage/bone ratio is higher, which can expand ultrasound vision and allow for better inspection of the intra-articular anatomical structure. Therefore, the features of ultrasound and children’s knees morphology allow for DLM diagnosis, and its classification is based on morphology and PRS.

Recently, only a few studies, where the diagnostic criteria were mainly based on a qualitative description of the ultrasound image’s characteristics, are available on the ultrasound diagnosis of DLM in children. Arifa Achour et al. observed the ultrasound images of eight children with DLM and believed that DLM could be diagnosed based on the following three features of ultrasound images: loss of normal triangular shape, abnormal elongation and thickness, and a heterogeneous central pattern. However, the examiner’s subjectivity significantly influences the judgement of these features. In our previous study, by setting quantitative ultrasound parameters to reflect the morphology of the lateral meniscus, we found that the width of the lateral meniscus and the angle formed by the chords of the upper and lower arc-shaped articular surfaces at the free edge had the highest diagnostic efficiency for DLM, and established quantitative ultrasound diagnostic criteria for DLM. However, the limitations of ultrasonography in observing the intra-articular anatomical structure of the adult knee prevented our previous study from exploring the diagnostic value of ultrasonography for DLM classification. Therefore, investigating the diagnosis and classification of DLM using ultrasound in children is necessary, considering its advantages in examining children and the suitability of the anatomical structure of children’s knees for the ultrasound.

By measuring and comparing the quantitative ultrasound parameters (the width of lateral meniscus, angle α and PRS) among normal lateral meniscus (NLM), IDLM and CDLM, and SPR-DLM and UPR-DLM, this study primarily aims to evaluate the diagnostic feasibility and validity of these parameters and develop quantitative ultrasound diagnostic criteria for DLM and its classification in children. These criteria favour early diagnosis, treatment planning and prognosis prediction in children with DLM.

**METHODS AND ANALYSIS**

**Study design**

Eligible participants will be enrolled according to the inclusion and exclusion criteria and sample size estimation. Based on the morphological features and PRS of the lateral meniscus in children, quantitative ultrasound parameters were set and measured in all participants. Based on the arthroscopy results, the participants were categorised into the following five groups: NLM, IDLM, CDLM, SPR-DLM and UPR-DLM. Differences in quantitative ultrasound parameters among the five groups were statistically analysed. Additionally, the diagnostic performance of each parameter was assessed and compared in terms of the area under the curve (AUC), sensitivity, specificity, and positive and negative predictive values. This study was registered in the Chinese Clinical Trial Registry (registration no. ChiCTR2200062000).

**Participants and eligibility criteria**

Participants will be included if they have undergone knee arthroscopy for knee symptoms such as pain, locking and limited extension, among others, and if they are no more than 14 years of age. However, participants will be excluded if they (1) refuse to participate in the study, (2) did not undergo arthroscopy, (3) did not undergo an ultrasound examination of the lateral meniscus within 3 days post-operatively, (4) have a history of surgery in the involved lateral meniscus, (5) have bucket handle tears or severe damage in the lateral meniscus verified by arthroscopy, or (6) have severe skin damage or fracture around the knee, knee dislocation, infection, tuberculosis, gout or rheumatoid arthritis.

**Parameters and measuring technique**

The quantitative ultrasound parameters that distinguish DLM and NLM will be set based on their morphological...
differences. According to our previous studies’ results, no significant difference in the thickness of the peripheral rim was found between the DLM and NLM. The width of the lateral meniscus directly reflects the meniscus size and is the key parameter for evaluating the meniscus morphology. Additionally, the angle $\alpha$ formed by the chords of the upper and lower arc-shaped articular surface of the lateral meniscus at the free edge, angle $\alpha=2 \arctan (0.5 \times \text{thickness/width}$, which comprehensively reflects the thickness and width of the peripheral rim, is the parameter with the maximum potential to reflect the lateral meniscus morphology. In children, the epiphysis of the tibia and femur is not closed, the ratio of cartilage to bone is higher and the joint space is wider, which enables the full observation of the knee intra-articular structure through ultrasound and the accurate measurement of the width and angle $\alpha$ of the lateral meniscus. For the width of the lateral meniscus, NLM is 11.09±1.42 mm, IDLM is 16.52±2.94 mm and CDLM is 24.10±2.17 mm. Coincidentally, the width of the DLM in children that can be observed through ultrasound is 19.85±3.63 mm. Therefore, measuring the width and angle $\alpha$ of the lateral meniscus in children using ultrasound can distinguish NLM from DLM and IDLM from CDLM. Ultrasound examinations will be performed as previously described. The examinee will be placed in the lateral decubitus or supine position with the knee extended and the lateral surface facing upwards. A Philips variable frequency (3.0–12.0 MHz) linear array probe, which is perpendicular to the lateral tibiofemoral joint line (red dashed line), represents the body surface locations of the anterior horn, body and posterior horn of the lateral meniscus. During knee extension to flexion, the peripheral rims of the anterior horn, body and posterior horn extrude from the articular cavity, and the apex angle of the triangle (angle $\alpha$) is the angle formed by the chords of the upper and lower arc-shaped surface chords at the free edge. The width and angle $\alpha$ of the anterior horn, body and posterior horn of the lateral meniscus, a total of six parameters, will be measured using ultrasound to distinguish NLM, IDLM and CDLM.

PRS is a key factor in surgical planning and prognosis prediction. The incidence of UPR-DLM is approximately 20%–70%, and it frequently requires arthroscopic repair. MRI evaluation of PRS is limited because it cannot dynamically measure the movement distance of the peripheral rim (MDPR). Therefore, Jose et al. used the dynamic observation of ultrasound to diagnose the Wisberg meniscus by measuring the MDPR of the posterior horn of the lateral meniscus. During knee extension, the peripheral rims of the anterior horn, body and posterior horn are located around the tibiofemoral line. However, during knee flexion, the peripheral rims of the anterior horn and body intrude into the articular cavity, while that of the posterior horn extrudes from the articular cavity. Therefore, measuring the MDPR from knee extension to flexion is important for evaluating the PRS. Ultrasound examination will be performed as follows. The patient will be placed in a supine position. A Philips variable frequency (3.0–12.0 MHz) linear array probe perpendicular to the lateral tibiofemoral joint line.
will be used to detect the peripheral rim of the anterior horn, body and posterior horn of the lateral meniscus. The distance from the peripheral rim to the tibiofemoral line will be measured for knee extension and at 60°, 90° and 120° for knee flexion (figure 3). The tibiofemoral line will serve as the reference line, and the part of the lateral meniscus beyond (extrusion) and within (intrusion) the tibiofemoral lines will be recorded as positive and negative values, respectively. MDPR is the absolute value of the difference between the distance from the peripheral rim to the tibiofemoral line during knee extension and the maximum distance from the peripheral rim to the tibiofemoral line during knee flexion (figure 4). The MDPR of the anterior horn, body and posterior horn of the lateral meniscus is observed and recorded in each position.

The ultrasound image of the lateral meniscus’s body in 0° in extension and 120° in flexion. The tibiofemoral line, connecting the lateral tibial and lateral femoral condyles. The yellow line is the peripheral rim of the lateral meniscus. The white dashed line is the vertical distance from the peripheral rim to the tibiofemoral line. The ultrasound image of the lateral meniscus’s body in 0° extension (A) and 120° flexion (B) shows the length of the white dashed line as 9.90 mm (A) and 5.20 mm (B). Therefore, the MDPR of the lateral meniscus is 4.70 mm, which is the absolute value of the difference between 9.90 mm and 5.20 mm.

of the lateral meniscus, which is a total of three parameters, will be measured using ultrasound to identify the SPR-DLM and UPR-DLM.

Sonographers from all research centres will receive unified training and a qualified certificate. Twenty-four sonographers will participate in this multicentre study and will consent to 2 days of training in the theory and practice of knee ultrasound. During training, 10 children will be examined by a team of four sonographers, with good interobserver and intraobserver consistency in measuring ultrasound parameters.

Each examinee will be evaluated independently by two sonographers (examining sonographers), and the ultrasound images will be saved for subsequent parameter measurement by two sonographers (measuring sonographers). The examining and measuring sonographers will be blinded to the medical records or clinical diagnoses of the examinees, and the examinees will be blinded to their clinical diagnoses.

**Grouping participants based on the diagnosis of the lateral meniscus and its classification under arthroscopy**

The Watanabe classification system classifies DLM into IDLM, CDLM and Wrisberg variants. Although this classification is simple and widely used, it is imprecise and does not provide sufficient information for guiding treatment or predicting prognosis. The Wrisberg meniscus is normal in morphology but differs from DLM in morphology and histology, with only high mobility of the posterior horn, which is inappropriate for classification as a DLM. However, the PRS is of great significance for treatment planning and prognostic prediction, and DLM is frequently complicated by a UPR, which is not considered in the Watanabe classification system. According to the classification of DLM proposed by Klingele et al., the lateral meniscus is categorized into NLM, IDLM and CDLM according to morphology and into SPR-DLM and UPR-DLM according to PRS. UPR-DLM can be further subcategorised into UPR-DLM in the anterior horn, body and posterior horn, according to the UPR location. This classification is simple and applicable for treatment planning and prognostic prediction. Therefore, the DLM classification in this study will be based on the Klingele classification system. The diagnosis of participants with DLM and its classification will be judged by the surgeon perioperatively, and four sports medicine physicians will independently observe arthroscopic surgery videos postoperatively. The diagnosis will be considered appropriate if at least four of the five physicians agree. Otherwise, the arthroscopic surgery video will be sent again to another four sports medicine physicians with a repeat judgement until the requirements are met.

The morphological classification criteria of the lateral meniscus will be based on the coverage area of the tibial plateau (coverage area), and the detail includes the following: coverage area <70% will be judged as NLM, 70% ≤ coverage area <90% as IDLM and coverage area ≥90% as CDLM. The PRS of the anterior horn,
body and posterior horn will be judged as SPR or UPR by arthroscopic probing from the anteromedial and anterolateral portals. UPR will be judged as follows: if meniscocapsular attachments are absent, if meniscocapsular attachments are deficient and the meniscus can be moved past the midpoint of the convexity of the lateral femoral condyle by the probe, or if the peripheral rim of the meniscus or meniscocapsular attachments have an unstable vertical tear. Otherwise, SPR will be judged.6

According to the arthroscopic diagnosis, participants will be diagnosed with NLM, IDLM, CDLM, SPR-DLM and UPR-DLM and correspondingly categorised into five groups.

Outcomes and data collection
Data on the participants’ age, sex, body mass index, involved knee and duration of symptoms will be obtained. Nine ultrasound parameters in the saved ultrasound images, including width, angle α, and MDPR of the anterior horn, body and posterior horn, will be measured independently by two groups of sonographers using a mouse-point cursor and computer automatic measurement system on the HD11-XE colour Doppler system (Philips, Tokyo, Japan), aiming at an accuracy of 0.01 mm and 0.01°. Each group of sonographers will be randomly selected to comprise two examining and two measuring sonographers. Furthermore, each parameter will be measured three times, and the results will be averaged and reported to two decimal places.

Data consistency will be tested using the κ consistency test. The κ consistency of the three sonographers’ measurements in each group will be analysed. If the κ consistency is satisfactory, the average of the three sonographers’ measurements will be calculated as the parameter measurement of the group. However, if the κ consistency is unsatisfactory, the measurement will be repeated until it is satisfactory. The κ consistency of the parameter measurements between the two groups will also be analysed. If the κ consistency between the two groups is satisfactory, the average of the parameter measurements of the two groups will be calculated as the parameter measurement for the statistical analysis. In contrast, if the κ consistency between the two groups is unsatisfactory, the examining sonographers in each group will re-examine the participant and save the ultrasound images for remeasurement until the κ consistency between the groups is satisfied.

Sample size calculation
Power analysis and sample size V.11 will be used to calculate the sample size according to the sample size estimation method of the diagnostic test.39 Based on the results of previous studies and preliminary experiments, the sensitivity and specificity of ultrasound in diagnosing the morphology and stability of the lateral meniscus in children are approximately 80%. However, based on Lee et al6 and the results of children’s knee arthroscopy in our hospital, IDLM and CDLM account for approximately 50% of DLM, and SPR-DLM and UPR-DLM account for approximately 50% of DLM. Therefore, the prevalence ratios of IDLM to CDLM and SPR-DLM to UPR-DLM are 1.0. The minimum sample size for participants with DLM is 96 cases, which would be 48 cases each for IDLM, CDLM, SPR-DLM and UPR-DLM under the following assumption: a power of 0.9 for hypothesis testing, a two-sided α of 0.05, and an expected sensitivity and specificity of 95%. The prevalence of DLM in the Asian population is approximately 17%,40 41 and children with DLM account for approximately 22.5% of all children with knee lesions admitted to our hospital. Therefore, the prevalence of DLM in children will be calculated as 20%. Moreover, if the sample size of DLM is met, the minimum sample size of NLM will be 480 cases, and the total sample size of NLM and DLM will be 576 (figure 5).

Figure 5 Flow diagram of the study design. CDLM, complete discoid lateral meniscus; DLM, discoid lateral meniscus; IDLM, incomplete discoid lateral meniscus; LM, lateral meniscus; NLM, normal lateral meniscus; SPR, stable peripheral rim; UPR, unstable peripheral rim.
Statistical analyses
Data will be timely and independently entered by two trained researchers and will be analysed using the SPSS V.23.0 (IBM Corp). Differences among NLM, IDLM and CDLM regarding the width and angle $\alpha$ of the anterior horn, body and posterior horn, and differences between SPR-DLM and UPR-DLM regarding MDPR will be analysed. Normally distributed continuous variables and non-normally distributed data will be described as mean±SD and median (IQR), which will be analysed using Student’s t-test and the Wilcoxon Mann-Whitney U test, respectively. Categorical variables will be described as frequencies (percentages) and analysed using Pearson’s $X^2$ and Fisher’s exact tests.

Receiver operating characteristic curves will be calculated to examine the relationship between the rate of true (sensitivity) and false (1–specificity) positives and to determine the AUC. The Youden index will be used to determine the optimal predictive cut-off for calculating the AUC. The diagnostic performance of each parameter will be assessed in terms of AUC, sensitivity, specificity, and positive and negative predictive values. Z-test will be used to compare AUC among parameters. AUC will be interpreted using four grades as follows: poor (<0.5), marginal (0.5–0.7), good (0.7–0.9) and better (>0.9). Statistical significance will be set at p<0.05.

Study commencement and duration
At the time of the preparation of this protocol paper, the study is being conducted simultaneously in our hospital and five other large medical centres, including West China Hospital, Sichuan University, the Fourth Medical Center of Chinese People’s Liberation Army General Hospital, Xinhua Hospital affiliated with the Shanghai Jiao Tong University School of Medicine, Yibin Hospital affiliated with the West China Hospital Sichuan University, Suning Central Hospital and the Third Hospital of Mianyang. As a sports medicine centre in southwest China, the annual volume of knee arthroscopy in children in our hospital is approximately 150–200 cases, and approximately 50–80 cases in the other five large medical centres. Therefore, the required sample size will likely be enrolled within 1–2 years, starting in August 2022 and ending in July 2024.

Patient and public involvement
None.

ETHICS AND DISSEMINATION
This study was approved by the Ethics Committee of West China Hospital, Sichuan University (approval no. 2022-923), and this approval covers all study hospitals. The study will be conducted in accordance with the published study protocol and the latest version of the Declaration of Helsinki. Written informed consent will be obtained from all participants before enrolment in the study. This study’s results will be published in peer-reviewed research journals and conference presentations.

DISCUSSION
DLM and its tears are among the most common causes of knee symptoms in children, and their diagnosis mainly depends on MRI. However, MRI cannot be performed dynamically in real time, which is unsuitable for evaluating the PRS of the DLM. Moreover, the morphology and vascular distribution of DLM in children differ from those in adults. Additionally, children do not tolerate a closed and high-noise MRI examination environment, easily generating motion artefacts and reducing MRI quality. The MRIs of DLM and its tears in children are unsatisfactory, with a sensitivity and specificity of 50% and 45%, respectively. Moreover, the long examination and waiting times for MRI are unsuitable for the early diagnosis and treatment of DLM in children. Therefore, it is particularly important to explore a new imaging examination method for diagnosing DLM and its tears in children and classify it according to morphology and PRS. Fortunately, ultrasonography has unique advantages that compensate for the disadvantages of MRI and meet these expectations. Ultrasound has been applied to diagnose meniscal tears and DLM with high accuracy. Additionally, the advantage of the real-time dynamic evaluation of ultrasound has made diagnosing PRS possible. In children, the advantages of ultrasound meet their unique requirements, and the anatomical characteristics of their knees better adapt to ultrasound, which is reasonable to speculate that ultrasound has great potential to diagnose DLM and its classification.

Although detecting DLM in children using ultrasound has been recently studied, almost no diagnostic test studies with high-level and prospective evidence have been conducted. Additionally, whether ultrasound can be used to classify DLM according to their morphology and PRS remains unclear. Notably, three quantitative ultrasound parameters are set, including width, angle $\alpha$ and MDPR of the lateral meniscus based on the morphological characteristics and motion range of the lateral meniscus, to diagnose DLM and its classification based on morphology and PRS in children. Therefore, this study’s results will confirm the feasibility of ultrasound for diagnosing DLM and its classification and develop quantitative ultrasound diagnostic criteria for the first time in children, which has important clinical value for early diagnosis, treatment planning and prognostic prediction of DLM in children.

A few studies on the diagnosis of DLM using ultrasonography have been published. In addition to our previous study, Arifa Achor et al qualitatively summarised the ultrasonic imaging characteristics from eight cases of children with DLM, and Yang et al explored the diagnostic value of convex and linear array probes for DLM in children. The present study is the first to use quantitative ultrasound parameters to diagnose DLM and its classification in children. More importantly, this study’s participants will be classified as NLM, IDLM, CDLM, SPR-DLM and UPR-DLM according to the arthroscopic diagnosis. Typically, ultrasound diagnostic accuracy is influenced.
by the examiner. Therefore, this study is a multicentre, prospective, double-blind diagnostic test, which is beneficial for minimising the impact of the sonographer's subjectivity on measurements.

Study participants in the NLM group will all be children with knee diseases rather than those with completely healthy knees, and knee diseases (such as joint effusion and cruciate ligament injury) may impact the measurements of ultrasound parameters. Additionally, whether in the DLM or NLM groups, some children will have lateral meniscal tears, particularly longitudinal tears, which may also affect the measurements. However, the participants will be children aged ≤14 years, but significant age differences exist, such as ages <8 and >10 years. This study will not conduct further stratified analysis according to age, which may affect the accuracy of the ultrasound diagnostic criteria for DLM when extended to all children.

Contributors SJY screened the literature, drafted the manuscript and critically revised it for important intellectual content. MZZ and LCW designed the trial and modified the manuscript. MY participated in the final approval of the version for publication. GC and JL contributed to the study's conception and design and revised the manuscript. All the authors have read and approved the final version of the manuscript.

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