Dynamic Magnetic Resonance Imaging Protocol: An Effective and Useful Tool to Assess Discoid Lateral Meniscus Instability in Children

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Objectives: One of the most common symptoms in cases of discoid lateral meniscus (DLM) in children is a "snapping" knee. The clock in extension, followed by a pop in flexion, perceived by the clinician, reflects the meniscal displacement caused by the peripheral meniscocapsular detachment. Standard magnetic resonance imaging (MRI) results in a 40% false-negative rate for detecting this instability. The hypothesis was that a dynamic MRI protocol could reduce the false negative rate and improve the efficiency of the MRI in detecting the direction of instability.

Methods: Eight DLM knees (8 patients) with snapping knees (grade 2 of Lyon's classification) were included in this monocentric prospective preliminary study in a referral center of pediatric orthopaedic surgery. Every patient underwent a dynamic MRI protocol with both T2-Fat-Sat sagittal and coronal slices, performed "after the clock" and again "after the pop" in a knee with standard 20 degrees of flexion during acquisition. All the MRI data were correlated with an arthroscopic description of the peripheral tear of the DLM according to Ahn's classification to assess for diagnostic accuracy.

Results: The standard MRI protocol resulted in a false-negative rate of 50% for detecting the direction of instability. The dynamic MRI protocol allowed the identification of, and classification of the meniscal instability, meniscal shift, and meniscocapsular tear in 8 of 8 patients (0% false-negative rate), perfectly correlated with arthroscopic findings.

Conclusion: This preliminary series, although short, allowed us to understand all the types of movements and lesions associated with the child's discoid meniscus. The detailed case analysis showed a strong benefit of such a protocol for planning the surgical suture procedure. The functionality and reliability of the dynamic MRI protocol is a good and method relatively simple method which does not require specific equipment, minimizing any additional cost compared with standard MRI.

Level of Evidence: Level IV.

Key Words: discoid lateral meniscus, children, MRI, meniscal instability, dynamic MRI, repair

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Discoid lateral meniscus (DLM) is the most common congenital meniscal abnormality.[1,2] Both the shape and the structure of the meniscus are altered in DLM,[3,4] and patients are usually asymptomatic until the meniscus, or the meniscal rim attachment, tears.[5]

In contrast to adult knees, symptomatic DLM in children and adolescents are usually of the complete discoid type,[6] and most commonly occur in association with some form of peripheral rim instability.[7–11] This instability reaches 95% of DLM in a recent pediatric series and the natural history of the pathology dictates that there is an increase in grade of clinical severity with time.[9,12] In children, the indication for repair in association with saucerization has increased over the past decade.[12,13]

Magnetic resonance imaging (MRI) allows clinicians to confirm the diagnosis of DLM,[14–17] but it has poor sensitivity in detecting the direction of instability. This is because MRI is performed on static images of knees in near full extension, hence explaining a 40% rate of false-negative results.[9,15] As a result, surgeons cannot anticipate before surgery whether they will have to perform an anterior, posterior, or, less frequently, circumferential suture repair. It is important to identify and classify the type of lesion, as this will help the surgeon preoperatively decide on what type of repair needs to be performed and, therefore, give the patient and parents more accurate information regarding the risks associated with the surgery.[9]

Hashimoto et al[18] have recently described performing MRI sequences in full extension and in full flexion in 2 cases of DLM. However, such sequences in children are often difficult and require a specific coil.

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The aim of the present study was to investigate a dynamic MRI protocol developed to classify DLM instability in case of a snapping knee (grade 2 of Lyon's DLM classification[9]). A traditional protocol was performed using one sequence after the "clock" and another after the "pop," so that the meniscal shift could be visible on at least one of the sequences. It was hypothesized that dynamic MRI could improve the sensitivity of MRI and reduce the number of false negatives in the detection of DLM instability.

METHODS

This prospective study was conducted at a single tertiary referral centre for pediatric knee surgery and imaging center, between June 2021 and December 2022. The study protocol was approved by the research ethics board of the Hôpital Femme Mère Enfant (Hospices Civils de Lyon) and Université Claude Bernard Lyon I.

Inclusion criteria were children from 3 to 16 years old with a symptomatic grade 2 DLM who underwent surgery (meniscoplasty and suture) in the referral center during the study period. Patients with mechanical symptoms such as locking, snapping, and loss of mobility were considered symptomatic and, therefore, treated with surgery, even in the absence of pain or where the functional impact was low.

DLM were classified according to the Lyon clinical grading system of instability.[9]

A stable knee without any symptoms is represented by grade 0. A history of a painful, locked knee is defined as a locked knee (grade 1), and grade 2 is defined as a snapping knee with a "clock and pop." In case of a flexion and/or extension deficit, the knee is classified as grade 3. Grade 4 was defined as an unblocked knee, meaning a knee with a history of snapping or blocked knee but currently without any symptoms at the clinical examination.

Snapping (grade 2) is characterized by the association of 2 distinct meniscal displacements, mainly in the sagittal plane, provoking different feelings according to the knee position. The "clock" is defined by a visible and audible vibration associated with meniscal displacement occurring during extension (tight anterior articular space); the "pop" is defined by a more discrete anterior meniscal protrusion during knee flexion (tight posterior articular space). These distinct feelings observed alternatively one after the other was due to meniscal dislocation or reduction at each position of flexion and extension, specified as habitual instability.[9]

Exclusion criteria included DLM knee with a different grade of instability, such as grade 1 (occasional instability) or locked/blocked knee with lack of flexion or extension (grade 3; as in such cases, a traditional MRI demonstrates the meniscal shift), and knees with previous surgery. Grade 1 and 3 DLMs were excluded because they represented a non-mobile meniscus without any "clock" and "pop." The dynamic protocol will be identical to the standard MRI protocol. Patients aged under 3 years of age were excluded as they usually needed an MRI under general anaesthesia.

The standard MRI protocol was performed before the dynamic sequences in 6 patients. In 2 patients, no static sequences were performed. These 2 patients did not have standard, nondynamic MRI (cases 2 and 8).

Magnetic Resonance Imaging Protocol

MRI was performed using Ingenia 1.5 T (Philips, Amsterdam, Holland). Sagittal and coronal Proton Density Fat-Sat sequences were performed, but the assessment was separated into 2 steps:

- First dynamic series: named "after clock."
  The radiologist placed the knee in full extension passively until the "clock" occurred. Then, the MRI was performed in this position with the knee at 10 to 15 degrees of flexion, by positioning the knee on a small foam cushion.
- Second dynamic series: named "after pop."

The radiologist placed the knee passively into full flexion until the "pop" happened. The knee is then re-extended to 10 to 15 degrees of flexion for acquisition, by positioning the knee on the same small foam cushion.

The average length for a dynamic knee MRI was around 20 to 25 minutes.

Each sequence was analyzed by 2 different clinicians independently (A.R. and A.C.), both pediatric musculoskeletal imaging specialists, blinded to the results of the "standard static" MRI that was performed.

The meniscal shift was classified according to the criteria proposed by Ahn et al,[19] determined by the presence and direction of the meniscal shift: no shift, anterior central shift (Figs. 1A and 2A), posterior central shift (Figs. 1B and 3B), and central shift.

Arthroscopic Evaluation

Meniscal and meniscocapsular assessment was performed at the beginning of the arthroscopy, before any saucerization. The meniscus was classified according to the Watanabe classification. Arthroscopic findings were also classified using the criteria proposed by Ahn et al[15]: meniscocapsular junction anterior horn type (Meniscocapsular-Anterior type; Fig. 4), meniscocapsular junction posterior horn type (MC-P type), or posterolateral corner loss type. Anterior-posterior complete peripheral meniscocapsular junction detachments were also classified as posterolateral corner type, although they did not correspond to the original description proposed by Ahn et al.[15]

Statistical Analysis

Demographic data were analyzed using descriptive statistics. Quantitative variables were expressed as median and SD, whereas categorical variables were expressed as count (percentage).

Variance analysis and Pearson χ^2 test were used to evaluate categorical variables as appropriate. The diagnostic accuracy of dynamic MRI was assessed using the sensitivity, specificity, positive predictive value, and negative predictive value. Statistical significance was set at $P < 0.05$.

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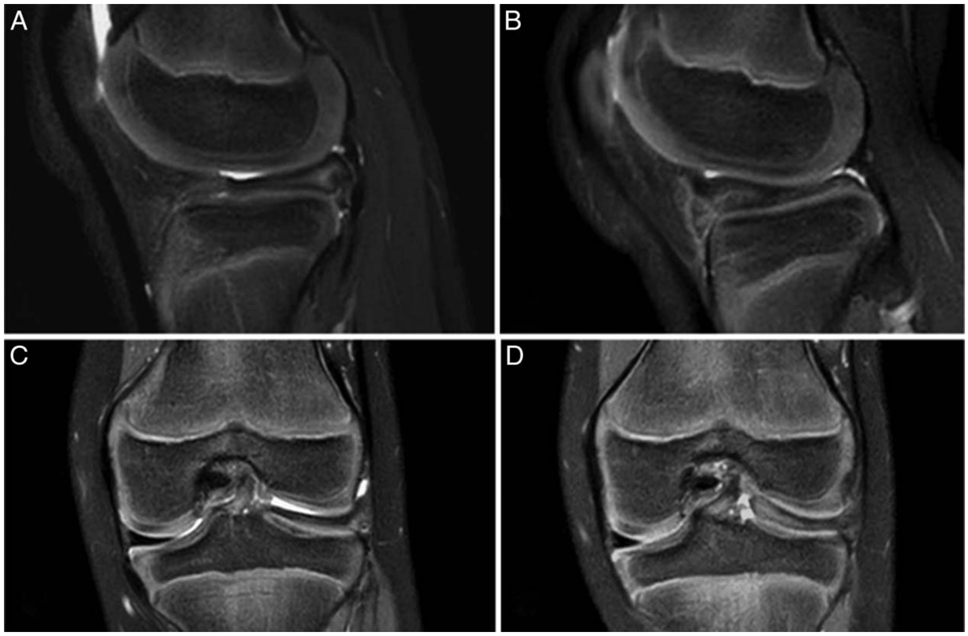

FIGURE 1. Case no. 1. MRI (T2 FS) sagittal (A and B) and coronal (C and D) acquisitions of a left knee during the dynamic protocol. Imaging reveals anterior and then posterior meniscal dislocation, respectively, after the "clock" (A and C) and after the "pop" (B and D). Arthroscopy confirmed a complete peripheral meniscal detachment (type C, according to Ahn). A, MRI (T2 FS, sagittal) performed after the "clock," showing posterior displacement of the lateral discoid meniscus (LDM). B, MRI (T2 FS, sagittal) performed after the "pop," showing anterior displacement of the LDM. C, MRI (T2 FS, coronal) performed after the "clock," showing the LDM without displacement in the frontal plane. D, MRI (T2 FS, coronal) performed after the "pop," showing medial displacement of the LDM. FS indicates Fat-Sat; MRI, magnetic resonance imaging.

FIGURE 2. Case no. 5. MRI (T2 FS, sagittal) acquisition of a left knee during the dynamic protocol, revealing a posteriorly dislocated meniscus after the "clock" (A) and a reduced meniscus after the "pop" (B). Arthroscopy confirmed an anterior peripheral meniscal detachment (MC-A type). A, MRI (T2 FS, sagittal) performed after the "clock," showing posterior displacement of the meniscus. B, MRI (T2 FS, sagittal) performed after the "pop," showing the meniscus without displacement in the sagittal plane. FS indicates Fat-Sat; MRI, magnetic resonance imaging.

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FIGURE 3. Case no. 7. MRI (T2 FS, sagittal) acquisition of a left knee during the dynamic protocol, revealing a reduced meniscus after the "clock" (A) and an anteriorly dislocated meniscus after the "pop" (B). Arthroscopy confirmed a posterior peripheral meniscal detachment (MC-P type). A, MRI (T2 FS, sagittal) performed after the "clock," showing posterior displacement of the meniscus. B, MRI (T2 FS, sagittal) performed after the "pop," showing the meniscus without displacement in the sagittal plane. FS indicates Fat-Sat; MRI, magnetic resonance imaging.

RESULTS

Demographic data about the 8 patients/knees is presented in Table 1. Standard MRI did not diagnose meniscal shift in 3 of 6 cases (50% false negative; cases 3, 5, and 7). The dynamic protocol allowed the identification of and classification of the meniscal instability, meniscal shift and meniscocapsular tear in 8 of 8 patients (0% false negative). The arthroscopic evaluation confirmed the MRI diagnosis of peripheric instability in these 8 patients (Fig. 2 and Fig. 4 for correlation). All DLM were complete (type 1 of the Watanabe classification).

The dynamic MRI was able to diagnose a complete peripheral meniscocapsular detachment when the MRI shift was anterior, medial and posterior on the 2 sequences (Fig. 1), isolated anterior meniscocapsular detachment when MRI showed isolated posterior meniscal shift (Fig. 2), and isolated posterior meniscocapsular detachment when MRI

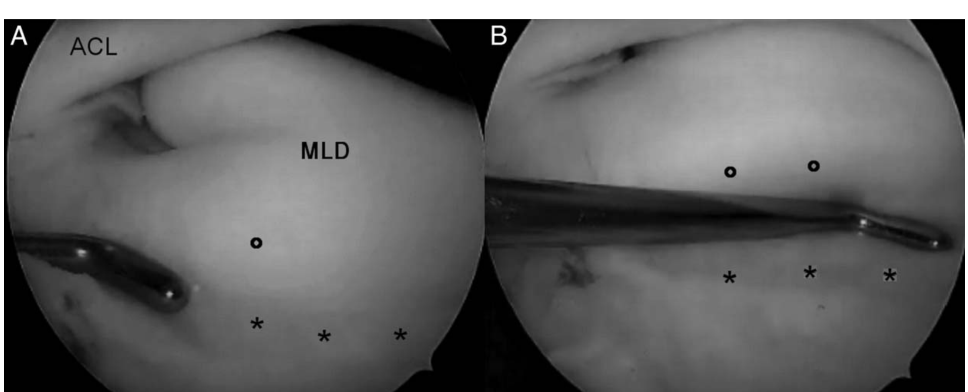

FIGURE 4. Case no. 5. Arthroscopic view of the lateral left knee compartment with complete DLM and meniscocapsular junction anterior horn type (MC-A type) detachment. A, An anterior gap filling with fibrous tissue is visible anteriorly to the DLM (*) as the anterior part of the meniscus is visible (°). B, Using the prob, the anterior part of the meniscus can move backwards. ACL indicates anterior cruciate ligament; MLD = DLM, discoid lateral meniscus.

TABLE 1. Demographic Data

Case	Sex	Side	Age (y)	Standard MRI	Dynamic MRI shift after "clock"	Dynamic MRI shift after "pop"	Arthroscopy
1	F	L	9	Anterior and medial shift	Posterior shift	Anterior and medial shift	Circumferential disinsertion (equal type C of Ahn)
2	F	L	6	—	Posterior shift	No shift	Anterior disinsertion
3	F	R	7	No shift	Posterior shift	No shift	Anterior disinsertion
4	F	L	8	Medial shift	Medial shift	Medial shift	Anterior disinsertion
5	F	L	5	No shift	Posterior shift	No shift	Fibrous anterior disinsertion (no gap)
6	F	R	14	Posterior shift	Posterior shift	No shift	Anterior disinsertion
7	F	R	6	No shift	No shift	Anterior shift	Posterior disinsertion
8	F	R	10	—	Posterior shift	No shift	Anterior disinsertion

Meniscal shift on MRI standard protocol, the 2 MRI dynamic protocol sequences and the classification of the tear arthroscopically (according to Ahn).
MRI indicates magnetic resonance imaging.

showed isolated anterior meniscal shift (Fig. 3). All meniscal shifts on MRI corresponded with the associated tear during the arthroscopic examination (Figs. 2 and 4 for correlation).

None of the patients had any meniscal shift on both sequences using the MRI protocol. The dynamic MRI, therefore, had a 100% sensitivity and specificity, and a 100% of true positive and true negative.

DISCUSSION

The most important finding of this preliminary study is that the use of this dynamic MRI protocol for the snapping knee (grade 2 of Lyon's classification) is highly effective in the diagnosis and classification of DLM instability, shift and tear type. Dynamic MRI can drastically reduce the false negative rate associated with a standard static MRI protocol in the diagnosis and classification of meniscal instability in children.

The rate of instability associated with DLM in children's series has dramatically increased over the last 20 years. MRI has been reported to be helpful in diagnosing DLM instability by visualization of meniscal shift.[19] In 2004, Adachi et al[20] reported 5 patients with a torn DLM treated using partial central meniscectomy in conjunction with the suture repair of the tear. Since this period, peripheral rim detachment associated with symptomatic DLM is better recognized. Despite an increasing rate of meniscal repair in recent series, the definition of instability and the indication for repair is still debated.[21,22] For some authors, the suturing of the DLM is almost routine in their attempts at meniscal preservation.[9,12] Whereas other authors, assess DLM stability by probing the residual meniscus after saucerization.[23]

It is important for the surgeons to assess the instability pattern at the time of surgical planning rather than intraoperatively. A better appreciation of the instability direction helps the surgeon determine the repair segment and give preoperative information for parents' consent. For instance, a meniscal repair for posterior detachment could pose a theorical risk of nerve damage after inside-out suture in contrary to anterior detachment. Moreover, the presence of a meniscal shift on MRI is easily understandable and could be helpful for parents in making the decision for surgery.

In the case of fixed dislocated DLM grade 3 of instability according to Lyon's classification,[9] the meniscus is shifted and fixed, so the meniscal shift is easily recognized on MRI. However, the situation is quite different in case of a snapping knee or grade 2 instability because the meniscus can be reduced or dislocated according to the direction of instability and the amount of knee extension/flexion seen with the timing of the sequence. In case of meniscocapsular-anterior type detachment, the sequence performed on a knee that has a "clock" in extension will help diagnose a posterior shift (Fig. 2A). If the sequence is performed in flexion or after the "pop" in flexion, the meniscus will be relocated, and the shift cannot be appreciated (Fig. 2B). The opposite is seen in a knee with Meniscocapsular-Posterior (MC-P) type detachment, the dynamic sequence performed on a knee that has a "clock" in extension will not demonstrate any shift (Fig. 3A), but MC-P type DLM will be anteriorly shifted after a "pop" with flexion (Fig. 3B). The meniscus position will then be variable, depending on how the knee is positioned after a "pop" or after a "clock" in the MRI. This description of the pathology demonstrates why 40% of grade 2 DLM are not dislocated on a conventional static MRI protocol of the knee, despite instability being found at the time of arthroscopy probing.[9,12] In the present preliminary study, 3 of 6 knees were a false negative using the standard static MRI protocol, which is in accordance with the literature.

Case number 1 (Fig. 1) allowed the identification of an unexpected situation, highlighting the efficacy of this dynamic MRI protocol. The standard protocol showed an anteromedial shift of the meniscus, suggesting it was due to a posterior meniscocapsular detachment. However, on the dynamic MRI imaging, the meniscal shift was anterior in the first sequence, and posterior in the second, which was due to a complete meniscocapsular detachment of the DLM, which was confirmed on arthroscopy to be a type C according to Ahn et al.[15] The dynamic protocol highlighted the need for a circumferential suture repair, utilizing an "outside-in" technique on the anterior segment, "inside-out" for the medial (and posterior), and an "all-inside" technique for the posterior segment adjacent to the posterior meniscal root. The surgeon was well prepared before the surgery to perform a circumferential suture due to the dynamic MRI.

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In case number 5 (Figs. 2 and 4), the standard static MRI protocol did not show any meniscal shift, but the dynamic one highlighted a posterior meniscal shift, due to an anterior meniscocapsular detachment. During arthroscopic surgery, the anterior part of the meniscocapsular junction did not demonstrate any gap or clear detachment, rather there was a continuous fibrous connection between the meniscus and the capsule. The failure of the anterior attachment would not have been appreciated by a non-pediatric knee–trained surgeon, and this incorrect assessment would have been in keeping with the false negative MRI, which failed to demonstrate a meniscal shift on the standard static MRI protocol imaging. The dynamic MRI highlighted to the surgeon that the anterior attachment, even if in continuity, is not mechanically functional, and, therefore, there is a need for anterior fixation.

Despite the absence of meniscal shift on the standard MRI, an experimented radiologist can sometimes visualize some indirect signs of meniscocapsular detachment, such as increased signal intensity, a gap or cyst at the meniscal attachment. These findings suggest there is a lack of peripheric meniscal insertion functionality. However, these indirect signs have a low intra and interreliability, and are predominantly for anterior meniscocapsular detachment, requiring subspeciality radiologist expertize.

Hashimoto et al[18] recently proposed another option for a dynamic MRI protocol to evaluate the DLM instability, with some sequences in full extension and in full flexion. However, depending on the age of the patient, the full flexion sequence can require the use of a specific MRI coil and results in low-quality imaging. Moreover, the full knee flexion is hard to maintain for the entire duration of the MRI imaging acquisition. Full flexion often causes discomfort, and movement artefacts will reduce the quality of the image. In the same way, the hyperextension position is uncomfortable and can be painful in case of recent anterior meniscocapsular detachment or in case of an anterior meniscal cyst. Their study was also of limited numbers, reporting on only 2 knees. In contrast, the presented technique in the present manuscript allows the use of a normal MRI coil to obtain good quality images, meaning no added cost; the knee position can be achieved in any standard MRI and is comfortable even if the knee is sensitive due to a meniscal tear.

Another alternative to this dynamic protocol can be the use of ultrasound imaging. A dynamic evaluation could be possible with some after "pop" and after "clock" imaging, but it is user-dependent and requires expertise by the ultrasonographer/radiologist. The second issue is that ultrasound images are less well understood by the surgeon and families than a meniscal shift seen on MRI. Although there is literature examining the efficiency of the ultrasound to diagnose DLM using segmental measurement,[24,25] however, to our knowledge, there is no literature looking at the efficiency of a dynamic ultrasound.

We acknowledge some limitations in this study. First, there is only a small number of patients included, and data collection for a bigger group is an aim for this protocol moving forward. However, all the cases presented in the manuscript demonstrated a large amount of variability in the DLM instability, shift and tear pattern, thus illustrating the potential of the dynamic protocol. While we will evaluate the protocol in larger numbers, we feel it is important to publish the protocol to allow other large groups to do the same. Second, this protocol needs a radiologist with pediatric experience and expertise in DLM who can maneuver the knee in flexion and extension to find the "clock" and "pop" clinically. Another option would be to have the orthopaedic surgeon place the knee in the correct position for the dynamic MRI protocol. Third, patients <3 years of age were not included because they need general anaesthesia to perform the MRI, but it may still be possible to perform this protocol on a patient under anaesthesia. However, the need for a precise diagnostic in <3 years old patients are limited because it is technically more difficult, and the presentation of snapping is limited in this age group. Fourth, for knee flexion during acquisition, the cushion was the same for all patients, so the degree of flexion could slightly vary according to limb length and thickness.

CONCLUSION

A dynamic MRI improved the diagnostic sensitivity of DLM shift and tear patterns compared with a standard static MRI. The improved sensitivity of the dynamic MRI gives the surgeon a better appreciation of the pathology, allowing the development of a more accurate surgical treatment strategy preoperatively. This improved understanding of the DLM pathology potentially improves the parental consent process and surgical efficacy. This method is simple and mainly indicated for the snapping knee in children; it could potentially drastically reduce the rate of false negative MRIs in failing to demonstrate the meniscal shift with standard imaging.

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