Knee Surgery, Sports Traumatology, Arthroscopy (2020) 28:855–861
https://doi.org/10.1007/s00167-019-05523-1

KNEE

# Magnetic resonance imaging can increase the diagnostic accuracy in symptomatic meniscal repair patients

**Emilie Faunø[1] · Ole Gade Sørensen[1] · Torsten Grønbech Nielsen[1] · Martin Lind[1] · Claus Tvedesøe[2]**

Received: 16 October 2018 / Accepted: 29 April 2019 / Published online: 9 May 2019


## Abstract

**Purpose** The purpose of this study was to evaluate meniscal repair healing in symptomatic patients through combined clinical assessment, magnetic resonance imaging (MRI) and re-arthroscopy. This study investigated the diagnostic accuracy of MRI and clinical assessment in determining failed meniscal repair in symptomatic meniscal repair patients, as verified by re-arthroscopy.

**Methods** Eighty patients were included. All had undergone a primary meniscal repair followed by an MRI and re-arthroscopy due to clinical symptoms of a meniscal lesion. A validated semi-quantitative scoring system was employed for identifying MRI-diagnosed healing failure. The clinical assessment was divided into joint swelling, joint-line tenderness, locking and a positive McMurray's test. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) of MRI and positive clinical findings were calculated using second-look arthroscopy as a standard.

**Results** The MRI results showed healing of 22 (27.5%) of the menisci and 58 (72.5%) unhealed menisci, whereas second-look arthroscopy identified 15 (19%) healed menisci and 65 (81%) unhealed menisci. The isolated MRI findings were 0.85, 0.8, 0.95 and 0.55 for sensitivity, specificity, PPV and NPV, respectively. The PPVs of the clinical assessments were 0.78, 0.85 and 0.94, with one, two and three clinical findings, respectively. A grade 3 MRI combined with joint-line tenderness presented a PPV of 0.98.

**Conclusion** A supplementary MRI will increase diagnostic accuracy when fewer than three clinical findings are present in a symptomatic meniscal repair patient. The clinical relevance of this finding is that MRI contributes to enhancing the diagnostic accuracy of an unhealed meniscal repair when there are limited clinical signs of meniscal pathology.

**Level of evidence** III.

**Keywords** Magnetic resonance imaging · MRI · Meniscal healing · Clinical assessment · Re-arthroscopy · Diagnostic value

## Introduction

Meniscal lesion is a common diagnosis among athletes as well as in the regular population [13, 18]. It can be treated by meniscal resection, but this involves an increased risk of osteoarthritis. Therefore, meniscal lesions are increasingly repaired to preserve joint integrity and limit the development of degenerative changes [2, 3, 8, 21, 26].

Meniscal healing after repair is reported in 80–85% of cases [1, 4, 12, 15, 27], which leaves up to one in five patients with an unhealed meniscus, potentially resulting in continuous symptoms and impaired function. When patients return for medical evaluation with a continuation or reoccurrence of symptoms after meniscal repair, there are different modalities for evaluating the meniscal status. Arthroscopy is the gold standard in meniscal healing assessment, but this

✉ Emilie Faunø
emilie@faunoe.dk

Ole Gade Sørensen
ole.gade.soerensen@vest.rm.dk

Torsten Grønbech Nielsen
torsten.gronbech.nielsen@auh.rm.dk

Martin Lind
martilin@rm.dk

Claus Tvedesøe
clautved@rm.dk

[1] Department of Sports Traumatology, Aarhus University Hospital, Palle Juul-Jensens Blvd. 99, 8200 Aarhus N, Denmark

[2] Department of Radiology, Aarhus University Hospital, Palle Juul-Jensens Blvd. 99, 8200 Aarhus N, Denmark

method is invasive and includes risks of complications [7]. Thus, the goal is achieving good evaluation accuracy with non-invasive methods to identify unhealed menisci after repair.

Specific clinical findings that characterise meniscal lesion have been described in the literature, such as knee locking, joint-line tenderness, swelling and a positive McMurray's test [5]. Magnetic resonance imaging (MRI) is the primary diagnostic imaging tool for the identification of meniscal lesions [11, 17]. It has been shown that MRI has a good ability to diagnose preoperative primary meniscal tears [17, 22, 23, 33, 34]. A study by Thomas et al. [28] showed that even with the diagnosis of primary meniscal lesion, MRI is not always indicated if the clinical examination strongly suggests pathology. The problem with using MRI for postoperative meniscal healing evaluation is that the rupture interface from the primary injury can be interpreted as a new lesion despite the adaptation from repair and healing at the tissue level [17, 19, 22, 25].

Miao et al. [17] found a low correlation between clinical findings and second-look arthroscopy for patients with meniscal repair, with a clinical healing rate of 70.8%. Steenbrugge [25] and Pujol [22] concluded that there was a high rate of false-positive MRI findings when diagnosing a lack of meniscal healing, reaching 38% in asymptomatic patients [25]. These studies dealt with an assessment of the sensitivity of MRI when diagnosing unhealed menisci in general and regardless of symptoms. However, in a clinical setting, it is important to know how to interpret the combination of imaging and clinical findings to identify meniscal repair failure. Presently, there is a lack of knowledge regarding how combined clinical findings and MRI can improve the diagnostic precision of meniscal repair failure assessment.

The present study investigates the extent to which MRI can identify unhealed meniscal lesions in symptomatic patients with previous meniscal repairs. In addition, the study investigates which clinical findings improve the diagnostic precision of unhealed menisci. The hypothesis is that MRI contributes to better sensitivity and positive predictive values (PPVs) in symptomatic patients with previous meniscal repairs compared to clinical assessment alone.

Therefore, the purpose of this study was to investigate the clinical relevance of whether an MRI is indicated based on the clinical findings of a symptomatic meniscus-repaired patient. The diagnostic value of MRI and clinical assessment based on re-arthroscopy findings has not previously been investigated in this particular patient group. Accordingly, this study endeavours to guide the clinician to decide whether an MRI is indicated in this group of patients.

## Materials and methods

The patient cohort was identified retrospectively using the National Health Care Classification System's surgery code for meniscal repair, whereby we identified all 425 patients who had undergone a meniscal repair at our institution during 2004–2012.

The indication for primary meniscal repair in all patients was a displaced longitudinal meniscus either isolated or in combination with an anterior cruciate ligament (ACL) lesion treated with ACL reconstruction.

Only patients with one or more symptoms of meniscal lesion after primary repair were included. The exclusion criteria included the lack of an MRI after primary meniscal repair, which excluded the majority of patients from our group because they did not return to the clinic after primary meniscal repair with symptoms of an unhealed meniscus. Furthermore, we excluded patients with more than one meniscal lesion in the same knee at the time of primary repair. The final patient cohort consisted of 80 patients.

### Clinical signs

The patient records were studied to identify the presenting symptoms and clinical signs after primary arthroscopic meniscal repair. The specific symptoms and clinical signs of the unhealed meniscus were determined as follows: (1) locking, (2) joint-line tenderness, (3) swelling and (4) a positive McMurray's test [5].

### MRI evaluation

A blinded radiologist re-examined the MRIs. The most frequent sequences used were sagittal short TI inversion recovery (Sag STIR), sagittal proton density (Sag PD), sagittal transverse relaxation (Sag T2*), coronal longitudinal relaxation (Cor T1) and axial STIR (Ax STIR). The meniscal lesions were graded on a scale of 0–3 (0: low signal intensity; 1: irregularly marginated intrameniscal signal; 2: linear signal not extending to articular surface; 3: linear signal intensity extending to surface). Only a grade 3 change was considered an MRI-diagnosed meniscal lesion [9].

### Re-arthroscopy

Re-arthroscopy recordings were used for collecting information on the meniscal status. Senior surgeons performed all re-arthroscopies, using a probe to evaluate the meniscus. The re-arthroscopy approach was used as the gold standard to which the clinical assessments and MRI findings were compared.

The project was approved by the Central Denmark Region Committees on Health Research Ethics (268/2017).

### Statistical analysis

The MRIs were evaluated statistically by calculating the PPV, negative predictive value (NPV), sensitivity and specificity of the MRI in general and for each MRI sequence. The clinical symptoms were evaluated in the same manner. Furthermore, different combinations of symptoms and MRI were evaluated to improve the diagnostic values. Stata 15 software was used for calculating the statistical outcomes.

## Results

### Patient characteristics

In the period of interest, 425 menisci were repaired. Of these patients, 266 were excluded due to the lack of an MRI after primary meniscal repair, 42 due to no re-arthroscopy and 36 either because of inaccessible record files and/or MRIs, new injuries or multiple meniscal lesions in the same knee. One patient died shortly after primary repair and was thus excluded as well.

The final cohort consisted of 80 patients with a median age of 23.8 (range 14–52) years at the time of primary meniscal repair (see Table 1 for patient details).

In 45% of the cases, the primary meniscal lesions were associated with ACL ruptures, which were reconstructed with the meniscal repair or 6 weeks after the meniscal repair. No patient had additional PCL ruptures. No patient had osteoarthritic changes, as characterised by MRI grade 3–4 cartilage lesions in more than one joint chamber.

The median time from injury or debut of symptoms to primary meniscal repair was 8 (range 1–132) months. The median time from primary meniscal repair to MRI was 12 (range 2–61) months.

### Re-arthroscopy

Re-arthroscopy identified 65 patients (81%) with a lack of meniscal healing and 15 (19%) with healed menisci.

### MRI

Overall, MRI was able to find 55/65 (85%) of the meniscal lesions (sensitivity). The specificity was found to be 80% (12/15). MRI assessment of the meniscal lesions showed a PPV of 0.95 (55/58) and an NPV of 0.65 (12/22). The same statistical values were calculated for each of the five most frequently used MRI sequences. They all ranged from 0.86 to 1.0 in the PPVs and 0.15–0.3 in the NPVs (Table 2).

**Table 1** Patient and injury details

| MRI/re-arthroscopy | +/+ | +/− | −/− | −/+ | Total (%) |
|---|---|---|---|---|---|
| Gender | | | | | |
| Male | 35 | 3 | 5 | 4 | 47 (59) |
| Female | 20 | 0 | 7 | 6 | 33 (41) |
| Side (knee) | | | | | |
| Right | 34 | 1 | 6 | 5 | 46 (58) |
| Left | 21 | 2 | 6 | 5 | 34 (42) |
| Side (meniscus) | | | | | |
| Medial | 50 | 3 | 10 | 5 | 68 (85) |
| Lateral | 5 | 0 | 2 | 5 | 12 (15) |
| Location | | | | | |
| Posterior horn | 49 | 3 | 10 | 9 | 71 (89) |
| Corpus | 5 | | 2 | 1 | 8 (10) |
| Anterior horn | 1 | | | | 1 (1) |
| Lesion pattern | | | | | |
| Vertical | 51 | 2 | 12 | 9 | 74 (93) |
| Incomplete | 3 | 1 | | 1 | 5 (6) |
| Flap tear | 1 | | | | 1 (1) |
| Repair | | | | | |
| Arrows[a] | 14 | 2 | 5 | 1 | 22 (28) |
| FastFix[b] | 41 | 1 | 7 | 9 | 58 (72) |

[a]Bionx, Blue Bell, PA, USA

[b]All-inside device, Smith & Nephew, Andover, MA, USA

**Table 2** Statistical values of magnetic resonance imaging (MRI) and different MRI sequences on meniscal healing after meniscal repair

| | PPV | NPV | Sensitivity | Specificity |
|---|---|---|---|---|
| MRI | 0.95 (55/58) | 0.55 (12/22) | 0.85 (55/65) | 0.8 (12/15) |
| Sag STIR | 0.93 (30/32) | 0.3 (6/20) | 0.68 (30/44) | 0.75 (6/8) |
| Sag PD | 0.88 (15/17) | 0.2 (10/49) | 0.28 (15/54) | 0.83 (10/12) |
| Sag T2* | 1[a] (16/16) | 0.27 (12/45) | 0.33 (16/49) | 1[a] (12/12) |
| Cor T1 | 1[a] (13/13) | 0.25 (13/51) | 0.25 (13/51) | 1[a] (13/13) |
| Ax STIR | 0.86 (6/7) | 0.15 (7/47) | 0.13 (6/46) | 0.88 (7/8) |

*PPV* positive predictive value, *NPV* negative predictive value, *Sag STIR* sagittal short T1 inversion recovery, *Sag PD* sagittal proton density, *Sag T2** sagittal transverse relaxation, *Cor T1* coronal longitudinal relaxation, *Ax STIR* axial short T1 inversion recovery

[a]No grade 3 MRI was falsely positive

### Clinical findings

The prognostic value of the clinical findings was as follows: the PPVs for swelling (30/34), joint-line tenderness (52/59) and a positive McMurray's test (21/24) were 0.88, whereas for locking, the PPV was 0.83 (20/24). Joint-line tenderness had a sensitivity of 0.8 (52/65), whereas locking only had a

**Table 3** Statistic values of different clinical findings in patients with symptoms after meniscal repair

| | PPV | NPV | Sensitivity | Specificity |
|---|---|---|---|---|
| Locking | 0.83 (20/24) | 0.19 (11/56) | 0.31 (20/65) | 0.73 (11/15) |
| Joint-line tenderness | 0.88 (52/59) | 0.38 (8/21) | 0.8 (52/65) | 0.53 (8/15) |
| Swelling | 0.88 (30/34) | 0.24 (11/46) | 0.46 (30/65) | 0.73 (11/15) |
| Positive McMurray's test | 0.88 (21/24) | 0.21 (12/66) | 0.32 (21/65) | 0.8 (12/15) |

*PPV* positive predictive value, *NPV* negative predictive value

**Table 4** Statistical values of increasing clinical findings in patients with symptoms after meniscal repair

| | PPV | NPV | Sensitivity | Specificity |
|---|---|---|---|---|
| One finding | 0.78 (14/18) | 0.45 (5/11) | 0.7 (14/20) | 0.56 (5/9) |
| Two findings | 0.85 (28/35) | 0.31 (9/29) | 0.58 (28/48) | 0.64 (9/14) |
| Three findings | 0.94 (15/16) | 0.23 (14/62) | 0.24 (15/63) | 0.93 (14/15) |
| Four findings | 1 (2/2) | 0.19 (15/78) | 0.03 (2/65) | 1 (15/15) |

*PPV* positive predictive value, *NPV* negative predictive value

sensitivity of 0.31 (20/65). The NPV was 0.38 for joint-line tenderness (8/21) but only 0.19 for locking (11/56) (Table 3).

The patients had varied clinical findings: 11 patients had none of the above-mentioned clinical findings but presented with other symptoms, 18 patients presented with one, 33 patients presented with two, 16 patients presented with three and 2 patients presented with four of the clinical findings (locking, joint-line tenderness, swelling and positive McMurray's test).

An increasing number of positive clinical findings was found to improve diagnostic precision. One clinical finding predicted a meniscal lesion with 78% (PPV = 14/18) accuracy, whereas three clinical findings increased the PPV to 94% (PPV = 15/16) (Table 4).

When combining MRI findings with clinical findings, the following diagnostic precisions were found: The highest PPV was found for a grade 3 MRI in addition to a positive McMurray's test, with a PPV of 1 (17/17). The combination of grade 3 MRI and joint-line tenderness had a PPV of 0.98 (44/45), while grade 3 MRI in addition to swelling had the highest sensitivity, at 0.87 (26/30) (Table 5).

## Discussion

The most important finding of the present study regarding symptomatic meniscal-repaired patients was that the MRI of knees with previously repaired menisci had a PPV of 0.95 for the detection of non-healed menisci. This means that a grade 3 meniscal change seen on MRI predicts an arthroscopically verified meniscal lesion in 95% of cases. This is a high precision for MRI in diagnosing non-healed meniscal repair. It is important to keep in mind that the investigated cases consisted of patients who returned to the hospital with knee symptoms after meniscal repair. Therefore, the high PPV is only valid for symptomatic patients.

The low NPV of 0.55 is not very informative to the clinicians dealing with a symptomatic patient after meniscal repair. Therefore, it may be necessary to perform explorative re-arthroscopy, especially at multiple clinical signs of meniscal lesion.

The MRI sensitivity in this study was found to be 0.85. This signifies that MRI is capable of finding 85% of meniscal lesions in this specific group of patients. When looking at the different MRI sequences, the Sag STIR sequence had the highest sensitivity (0.68).

Sixty-five out of the cohort of 80 symptomatic patients in this study had a lack of meniscal healing verified by re-arthroscopy. This means that approximately 80% of the patients who presented postoperative symptoms of a non-healed meniscal repair actually did have a non-healed meniscal lesion.

Each clinical finding was associated with a high PPV (0.83–0.88). These calculations are independent of the number of clinical findings and do not represent isolated clinical findings, as most of the patients had more than one positive clinical finding.

**Table 5** Statistical values of combined positive MRI finding and clinical findings in patients with symptoms after meniscal repair

| | PPV | NPV | Sensitivity | Specificity |
|---|---|---|---|---|
| MRI + locking | 0.88 (15/17) | 0.29 (2/7) | 0.75 (15/20) | 0.5 (2/4) |
| MRI + joint-line tenderness | 0.98 (44/45) | 0.43 (6/14) | 0.85 (44/52) | 0.86 (6/7) |
| MRI + swelling | 0.96 (26/27) | 0.43 (3/7) | 0.87 (26/30) | 0.75 (3/4) |
| MRI + pos. McMurray's test | 1 (17/17) | 0.43 (3/7) | 0.81 (17/21) | 1 (3/3) |

*MRI* magnetic resonance imaging, *PPV* positive predictive value, *NPV* negative predictive value

The PPV increased with the number of clinical findings for the patient. If the patient had three clinical findings, the clinical assessment achieved a similar PPV (0.94) to that of MRI (0.95). However, if the patient only presented one (PPV = 0.78) or two (PPV = 0.85) clinical findings, an improvement of diagnostic accuracy could still be achieved with the addition of MRI. As seen in Table 3, the sensitivity decreases with an increasing amount of clinical findings. This simply reflects that the number of patients decreases with the increase of clinical findings.

The combination of MRI and different clinical findings was also investigated. In particular, the combination of a grade 3 MRI and a positive McMurray's test or joint-line tenderness resulted in a PPV of 1. However, this study population consisted of patients with symptoms and, therefore, the MRI PPV (0.95) already included at least one symptom or clinical finding.

The study reflects the clinical reality, and the results can be considered when a clinician must decide how to manage a patient with a previous meniscal repair who presents with on-going symptoms. An MRI does not improve diagnostic accuracy if three or more clinical findings are present. If only one or two clinical findings are present, an MRI contributes to further diagnostic information and an increase in the PPV.

Miao et al. [17] studied 81 patients with a total of 89 meniscal lesions. All the patients underwent primary repair followed by clinical assessment, MRI and second-look arthroscopy, regardless of symptoms. They found a total healing rate of 86.5% after arthroscopy. The healing rate based on clinical assessment was 70.8%. The MRI sequences presented PPVs ranging from 0.18 (Sag PD) to 0.83 (Cor T2) and sensitivities ranging from 0.42 (Cor T2) to 0.92 (Sag T1). These results differed from the results of the present study, which could be explained by the different study populations. Miao et al. [17] included patients regardless of their symptoms, whereas only symptomatic patients were included in the present study.

Steenbrugge et al. [25] reported clinical outcomes compared with MRI outcomes in 13 patients after meniscal repair in a 13-year follow-up study. The patients were asymptomatic and had fair-to-excellent clinical outcomes. MRI demonstrated hyperintense abnormal signals in 5 of 13 patients. They did not use second-look arthroscopy for evaluation. The abnormal signals could represent new asymptomatic meniscal tears or oedematous scar tissue [25]. Assuming the latter, we can state that the number of false-positive results is decreased when dealing with a symptomatic group of patients.

A study by Mustonen et al. [20] examined the MRI signals of 44 patients who had undergone meniscal repair with bioabsorbable arrows. Postoperative MRI showed that 26% of the patients had a grade 3 signal. These patients were not evaluated by second-look arthroscopy. Thus, it is not known whether these signals were due to lesions or scar tissue. However, it is known that there is a general healing rate after repair of 80–85%. Therefore, it can be assumed that a part of these grade 3 MRI signals is due to scar tissue and not meniscal lesions. The above-mentioned studies support the theory that scar tissue from a meniscal repair can give abnormal signals on an MRI that can be interpreted as a new or unhealed lesion.

Walz [32] substantiated this further by describing the challenges of MRI interpretation for a repaired meniscus. Ideally, the bright intrameniscal signal on an MRI indicating a meniscal lesion should resolve after repair. However, in reality, a complete resolution is rare. Especially in the first 2 years after the repair, fibrovascular granulation or scar tissue can cause the persistence of the bright signal, and this can be mistaken as indicating a non-healed lesion.

In a study by Pujol et al. [22], MRIs were performed on 23 patients 10 years after meniscal repair, and the researchers concluded that the scar tissue persisted and could not be differentiated from new lesions. This may indicate that the high diagnostic value of the MRI in our study occurred because the patients were all symptomatic, whereas the patients in Mustonen et al.'s [20] and Steenbrugge et al.'s [25] studies included symptomatic and asymptomatic patients. Our study indicated that the risk of being incorrect on the MRI interpretation of a failed meniscal repair is markedly decreased in symptomatic patients.

The time between injury and primary repair varied among the patients, but a study by Espejo-Reina et al. [10] demonstrated that there is a good clinical healing rate of 83% for meniscal repairs 2–60 months after injury. van der Wal et al. [30] found no significant difference in clinical outcomes in meniscal repairs < 2 weeks or > 12 weeks after injury. Other studies [14, 31] have shown better clinical outcomes in early repairs within 3–6 months after injury.

The time from primary repair to MRI also differed. There was a correlation between the postoperative grade 3 MRI signal and the time between the repair and MRI, indicating that the grade 3 signal decreases with time as a sign of healing [20]. Hence, an even higher MRI PPV could be expected if the MRIs in the present study were performed later.

Two different devices have been used in the cohort, but studies have shown that the healing rate does not differ significantly using sutures compared to arrows [6, 24], and even the MRI signal pattern is quite similar after using the two techniques [20].

A number of patients underwent ACL reconstruction in the same procedure as the meniscal repair or 6 weeks after. Therefore, it is possible that the knee symptoms after surgery originated from the ACL reconstruction rather than the meniscal repair, which blurs the symptoms and the actual meniscal status. However, studies have shown that there is no increased

MRI signal or decreased healing rate of repaired meniscal lesions in patients with operated ACLs compared to patients with intact ACLs [10, 16, 20, 21, 29].

This study has limitations. The data retrieval involved difficulties because of the retrospective design. This resulted in a number of patients with meniscal repairs being excluded, which may have caused a selection bias. In addition, no distinction was made between excluded asymptomatic patients and the few symptomatic patients who had no MRI performed after primary repair. Some of these patients had a re-arthroscopy directly due to strong clinical symptoms of meniscal lesion, and others had neither procedure performed. Both groups could have caused a selection bias. Another weakness is that MRI and re-arthroscopy were only performed on symptomatic patients and, therefore, no asymptomatic patients were included, which, combined with the small number of patients with healed menisci, made it difficult to determine the NPV and specificity.

This study reflects the clinical reality, where patients often present with associated diagnoses, such as ACL rupture, and this could explain some of the false-positive cases in which the clinical assessment and/or MRI indicated a lack of meniscal healing but re-arthroscopy invalidated this diagnosis. Despite the possible effect of ACL rupture and reconstruction, a high PPV of MRI in diagnosing non-healed menisci in symptomatic patients was found.

To provide results that can be used in a clinical situation, it is important to investigate a cohort characteristic of the typical scenarios of meniscal repair patients (isolated and with ACL reconstruction).

## Conclusion

In this study, MRI of previously repaired menisci in patients with symptoms of non-healed meniscus had a PPV of 0.95 for detecting a lack of meniscal healing. When examining a cohort of symptomatic meniscal repair patients, the PPV of the clinical assessment increased, with more clinical findings evident. A supplementary MRI would increase diagnostic accuracy when fewer than three of the clinical findings specified in the study are present. If the patient exhibits three or four clinical findings, there is no further increase in diagnostic accuracy to be achieved, and thus there is no need for an MRI.

**Funding** There has been no funding of this study.

### Compliance with ethical standards

**Conflict of interest** Emilie Faunø, Ole Gade Sørensen, Torsten Grønbech Nielsen, Martin Lind and Claus Tvedesøe declare that they have no conflict of interest.

**Ethical approval** The project was approved by the Central Denmark Region Committees on Health Research Ethics (268/2017).

## References

1. Ahn JH, Lee YS, Yoo JC, Chang MJ, Koh KH, Kim MH (2010) Clinical and second-look arthroscopic evaluation of repaired medial meniscus in anterior cruciate ligament-reconstructed knees. Am J Sports Med 38:472–477
2. Ahn JH, Wang JH, Yoo JC (2004) Arthroscopic all-inside suture repair of medial meniscus lesion in anterior cruciate ligament—deficient knees: results of second-look arthroscopies in 39 cases. Arthroscopy 20:936–945
3. Alford JW, Lewis P, Kang RW, Cole BJ (2005) Rapid progression of chondral disease in the lateral compartment of the knee following meniscectomy. Arthroscopy 21:1505–1509
4. Barber-Westin SD, Noyes FR (2014) Clinical healing rates of meniscus repairs of tears in the central-third (red-white) zone. Arthroscopy 30:134–146
5. Barrett GR, Field MH, Treacy SH, Ruff CG (1998) Clinical results of meniscus repair in patients 40 years and older. Arthroscopy 14:824–829
6. Bryant D, Dill J, Litchfield R, Amendola A, Giffin R, Fowler P et al (2007) Effectiveness of bioabsorbable arrows compared with inside-out suturing for vertical, reparable meniscal lesions: a randomized clinical trial. Am J Sports Med 35:889–896
7. Cancienne JM, Mahon HS, Dempsey IJ, Miller MD, Werner BC (2017) Patient-related risk factors for infection following knee arthroscopy: an analysis of over 700,000 patients from two large databases. Knee. https://doi.org/10.1016/j.knee.2017.02.002
8. Chung KS, Ha JK, Yeom CH, Ra HJ, Jang HS, Choi SH et al (2015) Comparison of clinical and radiologic results between partial meniscectomy and refixation of medial meniscus posterior root tears: a minimum 5-year follow-up. Arthroscopy 31:1941–1950
9. Crues JV 3rd, Ryu R, Morgan FW (1990) Meniscal pathology. The expanding role of magnetic resonance imaging. Clin Orthop Relat Res 252:80–87
10. Espejo-Reina A, Serrano-Fernandez JM, Martin-Castilla B, Estades-Rubio FJ, Briggs KK, Espejo-Baena A (2014) Outcomes after repair of chronic bucket-handle tears of medial meniscus. Arthroscopy 30:492–496
11. Haims AH, Katz LD, Ruwe PA (1998) MR arthrography of the knee. Semin Musculoskelet Radiol 2:385–396
12. Haklar U, Donmez F, Basaran SH, Canbora MK (2013) Results of arthroscopic repair of partial- or full-thickness longitudinal medial meniscal tears by single or double vertical sutures using the inside-out technique. Am J Sports Med 41:596–602
13. Hede A, Jensen DB, Blyme P, Sonne-Holm S (1990) Epidemiology of meniscal lesions in the knee. 1,215 open operations in Copenhagen 1982–84. Acta Orthop Scand 61:435–437
14. Krutsch W, Zellner J, Baumann F, Pfeifer C, Nerlich M, Angele P (2017) Timing of anterior cruciate ligament reconstruction within the first year after trauma and its influence on treatment of cartilage and meniscus pathology. Knee Surg Sports Traumatol Arthrosc 25:418–425
15. Kubiak G, Fabis J (2010) Clinical results of meniscus repair. Ortop Traumatol Rehabil 12:28–40
16. Martin-Fuentes AM, Ojeda-Thies C, Vila-Rico J (2015) Clinical results following meniscal sutures: does concomitant ACL repair make a difference? Acta Orthop Belg 81:690–697
17. Miao Y, Yu JK, Ao YF, Zheng ZZ, Gong X, Leung KK (2011) Diagnostic values of 3 methods for evaluating meniscal healing

status after meniscal repair: comparison among second-look arthroscopy, clinical assessment, and magnetic resonance imaging. Am J Sports Med 39:735–742
18. Mitchell J, Graham W, Best TM, Collins C, Currie DW, Comstock RD et al (2016) Epidemiology of meniscal injuries in US high school athletes between 2007 and 2013. Knee Surg Sports Traumatol Arthrosc 24:715–722
19. Muellner T, Egkher A, Nikolic A, Funovics M, Metz V (1999) Open meniscal repair: clinical and magnetic resonance imaging findings after twelve years. Am J Sports Med 27:16–20
20. Mustonen AO, Tielinen L, Lindahl J, Hirvensalo E, Kiuru M, Koskinen SK (2006) MRI of menisci repaired with bioabsorbable arrows. Skelet Radiol 35:515–521
21. Paxton ES, Stock MV, Brophy RH (2011) Meniscal repair versus partial meniscectomy: a systematic review comparing reoperation rates and clinical outcomes. Arthroscopy 27:1275–1288
22. Pujol N, Tardy N, Boisrenoult P, Beaufils P (2013) Magnetic resonance imaging is not suitable for interpretation of meniscal status ten years after arthroscopic repair. Int Orthop 37:2371–2376
23. Rastegar S, Motififard M, Nemati A, Hosseini NS, Tahririan MA, Rozati SA et al (2016) Where does magnetic resonance imaging stand in the diagnosis of knee injuries? J Res Med Sci 21:52
24. Spindler KP, McCarty EC, Warren TA, Devin C, Connor JT (2003) Prospective comparison of arthroscopic medial meniscal repair technique: inside-out suture versus entirely arthroscopic arrows. Am J Sports Med 31:929–934
25. Steenbrugge F, Verstraete K, Verdonk R (2004) Magnetic resonance imaging of the surgically repaired meniscus: a 13-year follow-up study of 13 knees. Acta Orthop Scand 75:323–327
26. Stein T, Mehling AP, Welsch F, von Eisenhart-Rothe R, Jager A (2010) Long-term outcome after arthroscopic meniscal repair versus arthroscopic partial meniscectomy for traumatic meniscal tears. Am J Sports Med 38:1542–1548
27. Tachibana Y, Sakaguchi K, Goto T, Oda H, Yamazaki K, Iida S (2010) Repair integrity evaluated by second-look arthroscopy after arthroscopic meniscal repair with the FasT-Fix during anterior cruciate ligament reconstruction. Am J Sports Med 38:965–971
28. Thomas S, Pullagura M, Robinson E, Cohen A, Banaszkiewicz P (2007) The value of magnetic resonance imaging in our current management of ACL and meniscal injuries. Knee Surg Sports Traumatol Arthrosc 15:533–536
29. Tielinen L, Lindahl J, Koskinen S, Hirvensalo E (2007) Clinical and MRI evaluation of meniscal tears repaired with bioabsorbable arrows. Scand J Surg 96:252–255
30. van der Wal RJ, Thomassen BJ, Swen JW, van Arkel ER (2016) Time interval between trauma and arthroscopic meniscal repair has no influence on clinical survival. J Knee Surg 29:436–442
31. Venkatachalam S, Godsiff SP, Harding ML (2001) Review of the clinical results of arthroscopic meniscal repair. Knee 8:129–133
32. Walz DM (2016) Postoperative imaging of the knee: meniscus, cartilage, and ligaments. Radiol Clin N Am 54:931–950
33. Wong KP, Han AX, Wong JL, Lee DY (2017) Reliability of magnetic resonance imaging in evaluating meniscal and cartilage injuries in anterior cruciate ligament-deficient knees. Knee Surg Sports Traumatol Arthrosc 25:411–417
34. Yan R, Wang H, Yang Z, Ji ZH, Guo YM (2011) Predicted probability of meniscus tears: comparing history and physical examination with MRI. Swiss Med Wkly 141:w13314