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Evaluation of meniscal repair with serial magnetic resonance imaging: a comparative study between conventional MRI and indirect MR arthrography

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Abstract

Objective: To prospectively investigate the healing process of meniscal repair with plain magnetic resonance imaging (MRI) and indirect MR arthrography and to compare the two methods. *Materials and methods:* Twenty patients with an arthroscopic meniscal repair without clinical symptoms underwent conventional and indirect MR arthrography of the affected knee, 3, 6 and 12 months after the index operation applying a T1-w Spin Echo sequence in three planes. The size of the tear gap was measured on transverse images. The signal-to-noise ratio and the configuration of the abnormal signal were evaluated in the coronal images. *Results:* All patients demonstrated abnormal signal intensity at the side of the meniscal repair. The size of the gap at the previous tear side, reduced significantly by 45 and 40% on conventional MRI and indirect MR arthrography respectively, from 3 months to 1 year ($P < 0.05$). The signal-to-noise ratio of the intrameniscal abnormal signal reduced significantly and approximately 50% from 3 to 6 months, and from 6 to 12 months postoperatively, as demonstrated with indirect MR arthrography. However, as opposed to normal meniscus, the signal-to-noise ratio of the abnormal area remains 5.5 times higher 12 months postoperatively. In contrast, the reduction of signal-to-noise ratio of the abnormal area at conventional MRI was not significant even from 3 to 12 months. In 90% of the cases, the indirect MR arthrography showed the intrameniscal abnormal signal on plain MRI, to extend to the articular surface as opposed to 25% on plain MRI. *Conclusion:* With indirect MR arthrography, the natural process of meniscal healing can be evaluated. Significant reduction of the size of the tear gap and significant reduction of the signal-to-noise ratio of the abnormal signal as well as its configuration are the main parameters interpretating the normal healing process.

Keywords: Magnetic resonance imaging; Meniscal repair; Assessment of healing; Indirect MR arthrography

1. Introduction

The role of the meniscus in both the function and longevity of the knee joint has been well established [1–3]. Therefore preservation of meniscal tissue has become an essential goal in arthroscopic knee surgery. Meniscal repair, for vertical peripheral tears is the treatment of choice, particularly in young patients, to avoid the deleterious effects of partial or total meniscectomy [4,5].

Assessment of meniscal status after repair either healed or not, is important for the surgeon, in order to inform the patients whether they could increase their activities or if they could participate in sports. Postoperative assessment of meniscal repairs, has been based predominantly on clinical evaluation [6–8].

Other more objective methods such as arthrography [9] and second look arthroscopy are invasive, and therefore magnetic resonance imaging (MRI) has been proposed as a means to assess meniscal repair. Although MRI has been proven useful in the evaluation of primary meniscal injuries, its role in the postoperative evaluation of meniscal healing is still questioned. In fact many authors found that conventional MRI is unsuitable and unreliable for diagnosis of the healing process of a repaired meniscus [10–12].

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In an attempt to improve the accuracy of MRI for diagnosing meniscal healing, the use of direct MR arthrography, which involves the injection of intraarticular contrast material, or indirect MR arthrography, which involves the intravenous administration of paramagnetic contrast agent, have been proposed [13–17]. Since diagnostic ability of direct and indirect MR arthrography is similar, the use of indirect MR arthrography has been proposed because of its less-invasive nature [14]. Although several investigators have used these methods to evaluate meniscal status after resection or repair, there have been no studies focused on the serial changes in MRI signal of the repaired menisci using conventional MRI and indirect MR arthrography.

Therefore, it was the purpose of this study to prospectively analyze the MRI signals emitted from repaired menisci at various times intervals, in clinically asymptomatic patients who have undergone arthroscopic meniscal repair in an effort to evaluate the healing process, using conventional MRI and indirect MR arthrography. It was our hypothesis that the healing process of meniscal repair could be evaluated with serial MRI and that indirect MR arthrography could be more sensitive to assess the healing process.

2. Materials and methods

2.1. Patients and inclusion criteria

Thirty-two consecutive patients with an arthroscopically established diagnosis of a full-thickness vertical meniscus tear, were enrolled in the study and were all treated with arthroscopic meniscal repair. Inclusion criteria were: (a) vertical full-thickness tear greater than 10 mm in length, (b) location of the tear less than 6 mm from the meniscocapsular junction, (c) no former meniscus surgery and (d) no evidence of arthritis during arthroscopy. Because it is known that meniscal repairs do better in stable knees, anterior cruciate ligament (ACL) deficient knees were reconstructed using patella tendon or semitendinosus autograft, at the time of the meniscal repair. Furthermore, postoperatively if there was a question of a recurrent meniscal pathologic condition according to the clinical examination, the patient was excluded from the study.

Twenty-two of these patients (22 meniscal repairs) gave informed consent and agreed to undergo conventional MRI and indirect MR arthrography of the affected knee, 3, 6 and 12 months after the index operation.

2.2. Clinical evaluation

Each patient was assessed clinically at 3 and 6 weeks and 3, 6, 9 and 12 months postoperatively. Using Barrett et al.'s criteria [8] a repaired meniscus was considered clinically healed, if there was no joint line tenderness, no effusion and a negative McMurray's test. If one or more of these parameters was present, the result was classified as a failure. In addition a clinical evaluation using the Lysholm knee score was performed preoperatively as well as postoperatively. The Lysholm knee evaluation form was designed to score knee symptoms and function. The results according to the Lysholm score (0–100 points) were graded as excellent (>94 points), good (84–94 points), fair (60–83 points) and poor (<60 points).

2.3. Imaging and analysis

MR imaging of the knee was performed with a 1.0-T MR imager (Philips Intera; Philips Ìedical Systems, Best, The Netherlands) by using a quadrature coil. The MR imaging protocol included one pulse sequence (T1-w Spin Echo) in sagittal, coronal and transverse planes, before and after IV contrast administration (0.1 mmol/kg gadopentetate dimeglumine). Imaging parameters were as follows: 550/15 (TR ms/TE ms), matrix of 304 × 512, field of view 16 cm × 14 cm, four signal excitations, 4 mm slice thickness for the coronal and sagittal acquisitions and 500/20 (TR msec/TE msec), matrix of 304 × 512, field of view 16 cm × 14 cm, three signal excitations, 3 mm slice thickness for the transverse acquisition. MRI examinations were performed at 3, 6, and 12 months after surgery. No fat suppression was applied to avoid artefacts from previous operation and/or ACL reconstruction.

Three radiological parameters were evaluated: (1) intrameniscal signal intensity (IMSI) at the site of the repaired area was recorded. The maximum diameter of the IMSI was measured by one radiologist in the transverse images. (2) Signal intensity-to-noise ratio (SNR) of the IMSI was measured in the coronal images in all MRI examinations. SNR was also measured in the normal meniscus. (3) The IMSI configuration was evaluated qualitatively by one senior musculoskeletal radiologist in the coronal images with regard to accepted grading classification (I-IV). The non-paired *t*-test was used for comparison with regard to the IMSI thickness and SNR between time intervals. The paired *t*-test was used for comparison of the pre- and postoperative Lysholm score. Significance was set at $P < 0.05$.

3. Results

Physical examination revealed that, 2 out of 22 patients (9%) had tenderness on joint line palpation and therefore, they were excluded from the study. Thus, 20 patients (20 meniscal repairs) constitute the subjects of this report.

Fourteen men (70%) and six women (30%) were included in the study population. The average age at the time of meniscal repair was 24.3 years (range, 16–42 years). Eight (40%) patients suffered from isolated meniscal tear and underwent only meniscal repair, whereas 12 (60%) patients underwent both meniscal repair and arthroscopic ACL reconstruction.

There were 13 right knees (65%) and 7 left knees (35%). The medial meniscus was affected in 18 cases (90%) and the

lateral meniscus in 2 cases (10%). Eleven (55%) meniscal tears were located within a rim width of <3 mm (red–red zone), whereas 9 (45%) within a rim width of 3–6 mm. The meniscal tears' morphology included 20 (100%) longitudinal tears. The average length of the tear was 25.2 mm (range, 13–50 mm). Seven meniscal repairs (35%) were performed using the "outside-in" technique and vertical 0 PDS sutures, whereas five meniscal repairs (25%) were performed using the "inside-out" technique and vertical 2-0 Ethibond sutures. The remaining eight tears (40%) were repaired using an absorbable device (Rapid Lock anchor, Mitek Products, Westwood, MA USA) with an "all-inside" technique.

Physical examination revealed no symptoms of meniscal tears in all 20 (100%) patients. The Lysholm score increased to a mean value of 92.5 (range 65–100), which was statistically significant compared to the preoperative mean value of 53.6 (range 18–61), ($P < 0.001$, paired *t*-test). According to the results obtained from the Lysholm Knee Score, 13 patients (65%) had an excellent result and 7 patients (35%) a good result. All patients had returned to full time work.

3.1. Imaging results

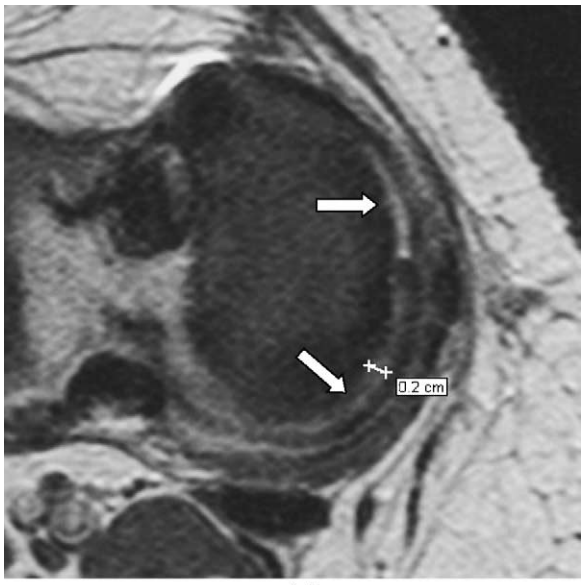
Measurements of the IMSI (tear gap) showed that the size of the gap in both conventional MRI and indirect MR arthrography, gradually reduced from 3 months to 1 year (Table 1) and this was statistically significant. There was a 0.78 and 0.73 mm reduction of the IMSI on conventional MRI and indirect MR arthrography respectively, during this time period (Figs. 1 and 2). The IMSI did not significantly reduce from 3 to 6 months. There were no differencies between the two methods regarding both the detection and the decrease of tear size at all stages of MRI follow-up.

The SNR of the normal meniscus was 3.7. The SNR of the IMSI 3 months postoperatively was 14.6 at conventional MR imaging. This was slightly decreased by the end of the first year (11.6) but it was not statistically significant.

Table 1
Size of the intrameniscal abnormal signal intensity (in mm) measured at different times of MRI examination

	Months			*P*-value
	3	6	12	
Conventional MRI	1.74 ± 0.7	1.52 ± 0.6	0.96 ± 0.5	Ns[a] 0.032[b] 0.013[c]
Indirect MR arthrography	1.83 ± 0.9	1.71 ± 0.6	1.1 ± 0.8	Ns[a] 0.025[b] 0.01[c]
P-value[d]	NS	NS	NS	

Statistical differences at various intervals.
[a] Three months versus 6 months.
[b] Three months versus 12 months.
[c] Three months versus 12 months.
[d] Statistical differences between the two methods.



(a)

(b)

Fig. 1. Normal healing process of repaired medial meniscus in serial MRI examinations of a 23-year-old woman with previous bucket-handle tear. (a) The contrast-enhanced T1-w Spin Echo at 3 months postoperatively, shows intense enhancement of the repaired medial meniscus (arrows). (b) The contrast-enhanced T1-w Spin Echo at 12 months postoperatively, shows reduced diameter at the side of repair (arrow).

In conrast, alterations of SNR of the IMSI on indirect MR arthrography were more intense (Fig. 3). As Table 2 shows there was a significant reduction of SNR of the IMSI from 3 months to 6 months, and from 6 months to 1 year. In comparison to normal meniscus, the SNR of the IMSI was 11 times higher 3 months postoperatively, and 5.5 times higher 12 months postoperatively. On the other hand, SNR of the IMSI at conventional MRI, was four times higher 3 months postoperatively, and reduced only to three times higher 12 months postoperatively in comparison to normal meniscus.

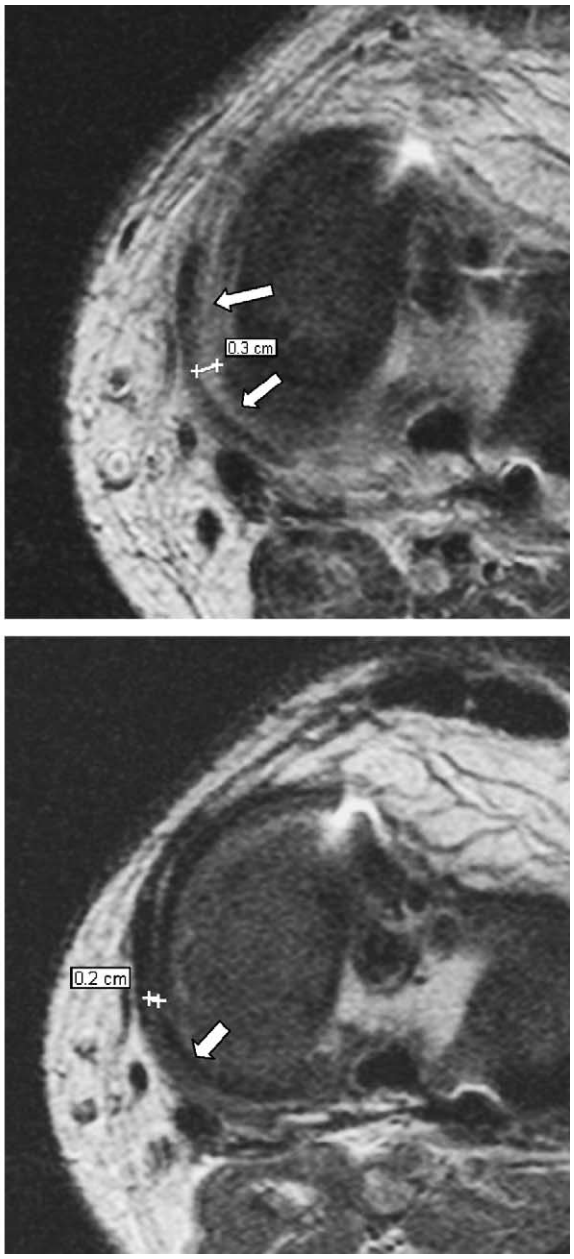


Fig. 2. Forty-three-year-old man with previous bucket-handle medial meniscus tear repaired with "outside-in" technique: normal healing process in serial MRI examinations. The ACL was also reconstructed arthroscopically. (a) The contrast-enhanced T1-w Spin Echo at 3 m postoperatively, shows intense enhancement of the repaired medial meniscus (arrows). (b) The contrast-enhanced T1-w Spin Echo at 1 year postoperatively, shows reduced diameter at the side of repair. The enhancement is hardly seen posteriorly (arrow).

All patients demonstrated IMSI at the side of the meniscal repair with both conventional MRI and indirect MR arthrography. Conventional MRI demonstrated IMSI similar to grade I or II of meniscal degeneration, in 75% of patients. In the rest 25%, the IMSI was extending to the articular surface. Indirect MRI arthrogram, revealed grade I or II IMSI in 10% of the patients and in the rest 90% extension to the articular surface (Figs. 3 and 4).

Table 2
Signal-to-noise ratio of the intrameniscal abnormal signal (repaired tear) at different times of MRI examinations

	Months			*P*-value
	3	6	12	
Conventional MRI	14.6 ± 4.3	13.7 ± 5.1	11.4 ± 3.9	NS[a] NS[b] NS[c]
Indirect MR arthrography	41.5 ± 11.1	28.7 ± 9.8	21.3 ± 7.5	0.02[a] 0.01[b] 0.035[c]
P-value[d]	0.001	0.001	0.004	

Statistical differences at various intervals.
[a] Three months versus 6 months.
[b] Three months versus 12 months.
[c] Six months versus 12 months.
[d] Statistical differences between the two methods.

Seven patients showed abnormal signal intensity in the medial collateral ligament in the first postoperative MRI examination. This area demonstrated intense enhancement after contrast medium administration. In all patients, normal or almost normal configuration of the medial collateral ligament was observed in the 6-month follow-up (Fig. 5).

4. Discussion

It is known that MRI is a non-invasive method to assess meniscal status and therefore easily accepted by patients. However, the evaluation of the meniscus after resection or repair is difficult to evaluate with MRI. Many authors proposed different, and not the classic MR criteria to differentiate repeat meniscal tears after meniscal resection [18]. This is because of the variable appearance of the meniscus after partial resection or repair, which is influenced by both location and degree of resection or repair [14].

The use of direct and indirect MR arthrography has been shown to increase the accuracy and specificity of MR imaging in the evaluation of the postoperative meniscus [13–17]. According to some studies there is no significant difference in diagnostic accuracy, among direct and indirect MR arthrography [14,17]. Because indirect MR arthrography, is a less-invasive procedure, and the presence of a physician and fluoroscopic guidance is not required, we selected this imaging approach in our study.

According to the literature the appearance of the meniscus after meniscal repair has a grade three signal intensity on MRI scans postoperatively in the majority of cases in the healing meniscus [10–12]. Farley et al. [19] suggested that the presence of grade three signal intensity within the postoperative meniscus was not an indicator of recurrent meniscal tear. Our findings are in agreement with the above mentioned publications since grade III IMSI was found in 25% of the asymptomatic patients with plain MRI and in 90% with indirect MR arthrography. Therefore, we tried to

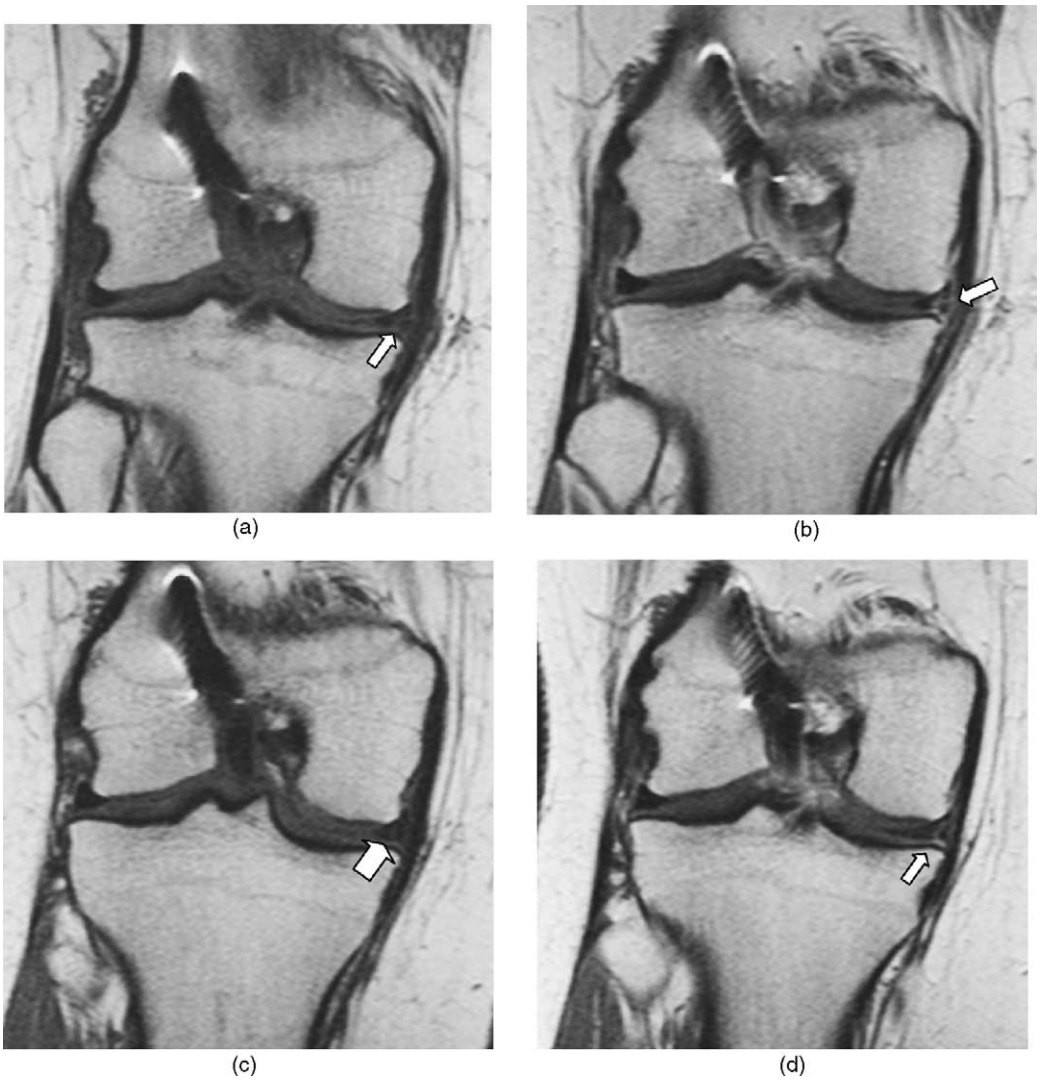


Fig. 3. Same patient as Fig. 1. (a) The coronal T1-w Spin Echo MR image at 3 m postoperatively, shows abnormal signal intensity at the site of previous medial meniscus tear (arrow). (b) The corresponding coronal contrast-enhanced T1-w Spin Echo MR image shows enhancement of the intrameniscal signal intensity extending to the meniscocapsular attachment (arrow). (c) The coronal T1-w Spin Echo MR image at 1 year postoperatively, shows reduced size of the intrameniscal signal as opposed to a (arrow). (d) The corresponding coronal contrast-enhanced T1-w Spin Echo MR image, shows enhancement of the intrameniscal signal intensity extending to the inferior articular surface (arrow).

contribute in establishing different criteria to diagnose a recurrent tear by demonstrating the normal healing process of meniscus repair.

Arnoczky et al. [10], in an excellent study found that during the normal healing of a repaired meniscus there is a gap of 1–2 mm between the repaired segments, which filled with a translucent tissue highly cellular and fibrovascular 3 months after repair. Six months postoperatively, the gap is gradually filled with the repair tissue showing evidence of fibrocartilagenous metaplasia, but it is still markedly different from the normal meniscal tissue. Using the transverse T1-w MR images in our study, it was possible to measure the gap between the repaired segments. We found a 45 and 40% reduction of the tear size on conventional MRI and indirect MR arthrography respectively, from 3 months to 1 year. Our results confirm in humans the above findings and indicate that the gradual filling of the gap, which is part of the normal course of meniscal healing, can be evaluated with both serial conventional and indirect MR arthrography. However, there were no significant differencies between the two methods.

The intravenous administration of gadolinium-based contrast material has been suggested as a means of increasing the conspicuity of joint fluid imbibition at the site of repair [17]. Furthermore, indirect MR arthrography has the potential to cause enhancement of vascular and cellular proliferation within the fibrovascular scar tissue that is seen histologically at the margins of torn or healing menisci [17,20]. Because of this, we theorize that the metaplasia of the repair tissue, from fibrovascular to fibrocartilagenous and fibrocartilage could be evaluated more effectively with the indirect MR arthrography. This was demonstrated in the

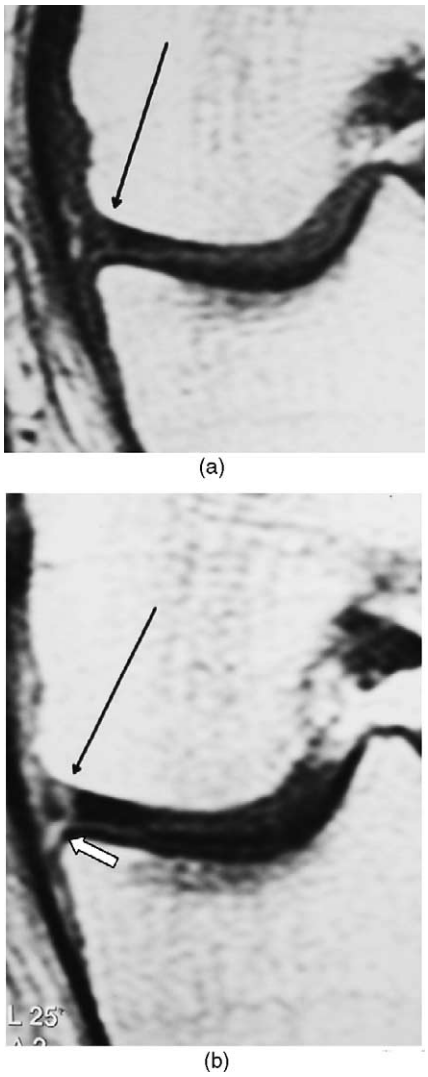


Fig. 4. Twenty-nine-year-old man with previous bucket-handle medial meniscus tear and "outside-in" repair. (a) The plain coronal T1-w Spin Echo image shows a subtle intrameniscal signal, at the site of the repaired bucket-handle tear (arrow). (b) The contrast-enhanced coronal T1-w Spin Echo image shows intrameniscal enhancement at the site of the repaired bucket handle tear extending to the superior (black arrow) and inferior articular surface (white arrow).

vast majority of our patients with intense enhancement at the side of the repaired tear.

We used the SNR of the IMSI as a factor to determine the process of meniscal healing. According to our findings, the SNR of the repaired tear reduced significantly and approximately 50% from 3 to 6 months, and from 6 to 12 months postoperatively, as demonstrated with indirect MR arthrography. However, in comparison to normal meniscus, the SNR of the tear remains 5.5 times higher 12 months postoperatively. Probably, this means that the remodelling of the repair tissue is a prolonged process, as it has been shown by other studies [10,20,21]. In contrast, the reduction of SNR of the repaired tear at conventional MRI was not significant even from 3 to 12 months. We believe that, our initial hy-

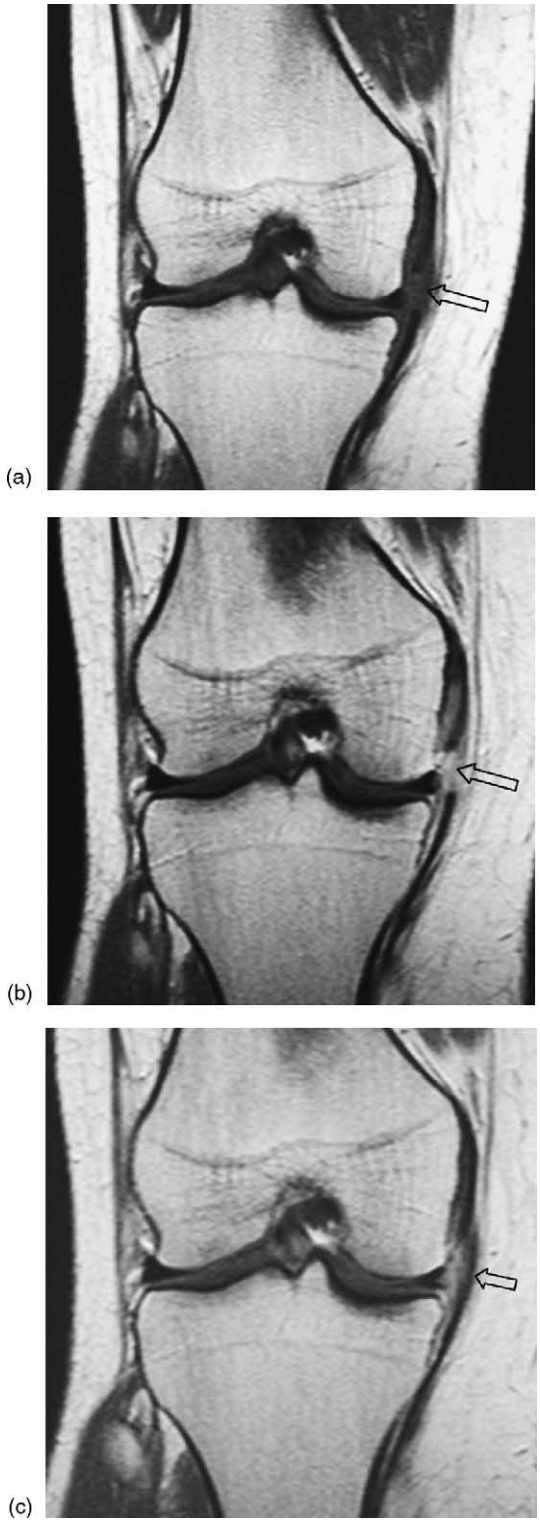


Fig. 5. Thirty-two-year-old woman with repaired vertical tear of the medial meniscus. (a) Coronal T1-w Spin Echo MR image 3m postoperatively, shows abnormal signal intensity in the medial collateral ligament (arrow). (b) The corresponding contrast-enhanced MR image demonstrates intense enhancement in the medial collateral ligament abnormal "gap" (arrow). (c) Coronal contrast-enhanced T1-w Spin Echo MR image 6 months postoperatively, shows almost normal configuration of the medial collateral ligament (arrow) with residual enhancement in the meniscocapsular attachment.

pothesis, that indirect MR arthrography is more sensitive in evaluating the healing process of a meniscal repair was confirmed. Tanaka et al. [22] using indirect MR arthrography also observed intrameniscal enhancement at the site of prior surgery 12 months after meniscal repair, similar. Our results suggest that more than 1 year is required for the remodeling of a repaired meniscus. Therefore, the rehabilitation after meniscal repair should not be aggressive during this period. We do not know when and if the repaired meniscus becomes normal on MRI scans. MRI studies with longer follow-up are needed to address this question.

An abnormal signal intensity area was observed in the medial collateral ligament in the first postoperative examination, in all patients who underwent meniscal repair with the "outside-in" technique. This MRI finding has never been described so far, to the best of our knowledge. To our opinion, this finding represents a tear of the medial collateral ligament, probably because of the multiple perforations of the ligament by the needles during arthroscopic meniscal repair, using this specific (outside-in) technique. The medial collateral ligament returned to normal appearance in the final postoperative MRI examination.

An limitation of our study is that our patients did not undergo second-look arthroscopy, which it is the standard of reference for evaluation of meniscal status. However, according to Morgan et al. [23] clinical examination seems to be a reliable method of evaluating the status of repaired menisci. In the above study, it was proved that clinical examination accurately predicted all failures in second look arthroscopy, with no false positives. In our study a repaired meniscus was considered healed if there was neither joint line tenderness, nor effusion or a positive McMurrey test, according to the strict clinical criteria of Barrett et al. [8]. Furthermore, it would not seem ethical to do a re-arthroscopy in the absence of any clinical symptomatology.

5. Conclusion

Arthroscopic meniscal repair is a common procedure in orthopaedic practice for the treatment of an injured meniscus. Following such surgery, it is important for the surgeon to know the state of the repaired meniscus, in order to inform patients whether they could increase their activities or not. With the proposed MRI technique, the natural process of meniscal healing can be evaluated. Significant reduction of the size of tear gap and significant reduction of SNR of the repaired tear are the two main parameters to establish healing by using indirect MR arthrography.

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