


# Role of MRI in predicting meniscal tear reparability

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## Abstract

**Objective** To elucidate the role of MRI in predicting meniscal tear reparability according to tear type and location in relation to vascular zones.

**Materials and methods** In this retrospective study, two readers evaluated 79 pre-surgical MRIs of meniscal tears arthroscopically treated with meniscectomy or meniscal re-

pair. Tears were classified according to type into vertical, horizontal, radial, complex, flaps and bucket handle and were considered reparable if the distance measured from the tear to the menisco-capsular junction was less than or equal to 5 mm. Predictions were compared with the surgical procedure performed in arthroscopy. We assessed the diagnostic performance of MRI, agreement between MRI and arthroscopy, and interrater agreement. Then, we conducted an ROC analysis on the distances measured by the first reader and built a multivariate logistic regression model.

**Results** MRI had a sensitivity, specificity, PPV, NPV and accuracy, respectively, of 85%, 79%, 86%, 76% and 83% in predicting meniscal tear reparability. Correct predictions for the specific tear pattern were 76% for vertical, 84% for horizontal, 88% for radial, 86% for complex, 84% for flaps and 86% for bucket handle. Agreement between the two readers' predictions and arthroscopy was good ( $k = 0.65$  and  $0.61$ , respectively). Inter-rater agreement was almost excellent ( $k = 0.79$ ). The ROC analysis revealed sensitivity and specificity of 73% and 83% with a cutoff value of  $<4$  mm ( $p < 0.001$ ). Anterior cruciate ligament injury and medial meniscal tear increased the likelihood of meniscal tear reparability.

**Conclusions** MRI can be a reliable and accurate tool to predict the reparability of meniscal tears, with higher prediction rates for bucket-handle tears.

The Institutional Review Board of the San Matteo Hospital-Pavia (Italy) approved this study

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## Introduction

Meniscal tears have an incidence of 160/100,000/year and cause at least 500,000 arthroscopic procedures per year in the

USA [1, 2], most of them consisting of partial meniscectomy or repair with sutures. Meniscus repair is recommended for tears occurring at the external third of the meniscus since it is the only vascularized region (also called the “red zone”) and may heal successfully [3]. The decision to repair is also strongly influenced by age, as younger subjects have better outcomes with decreased re-tear rates [4]. When meniscal repair is performed, the rehabilitation program is typically more intensive, with longer avoidance of weight bearing. Surgery is also more strenuous; for these reasons, an accurate prediction of meniscal reparability before arthroscopic assessment would be valuable information for both the patients and clinicians.

The tear pattern is a critical point. Vertical tears are more amenable to repair than all the others [5]. Horizontal tears often spread to the white zone and are less frequently repaired. Furthermore, they are common findings in asymptomatic subjects and could stay mechanically stable for years [6]. Incomplete radial tears are treated with debridement of the loose edges, while complete radial tears, mechanically equivalent to total meniscectomy, can be secured with sutures [7]. Complex tears, including multidirectional, fragmented or chronic degenerative tears, are not deemed reparable because of the poor chances of healing [8]. Flap tears are treated with removal of the torn fragment since, by definition, the white zone is violated. Bucket-handle tears may be repaired, but only if they are completely encompassed by the red-red zone.

Magnetic resonance imaging (MRI) is the actual standard of care to detect meniscal tears, reaching an accuracy value of up to 92% [9]. According to prior studies, MRI is a poor predictor of meniscal tear reparability with accuracy ranging from 60 to 74% [10, 11]. Accuracy rises up to 92–94% in selected populations with the same tear pattern, i.e., vertical and bucket-handle tears [12–14]. These studies considered different criteria, including the distance from the meniscocapsular junction to the tear, tear length and depth, and presence of an intact torn fragment. However, they have not taken the different tear patterns into consideration.

The aim of our study was to elucidate the predictivity of pre-surgical MRI for meniscal tear reparability, according to the tear pattern (i.e., vertical, horizontal, radial, complex, flaps and bucket handle) and the distance from the menisco-capsular junction to the tear.

## Methods

### Patients

We obtained the approval of the Institutional Review Board of our hospital. Informed consent was waived for this retrospective HIPAA-compliant study. We considered all the consecutive patients undergoing arthroscopic surgery for meniscal tears in the period from 1 January 2011 to 30 April 2016 at

the authors' institution. Inclusion criteria were as follows: arthroscopic surgical repair of meniscal tears; the presence of an MRI of the knee performed at our hospital within 4 months before surgery. A second group of 60 consecutive patients operated on with meniscectomy within the same period was considered the control group. The inclusion criteria for the control group were as follows: arthroscopic procedure of meniscectomy; age less than 45 years; availability of an MRI performed at our hospital. Eleven patients were excluded because the pre-surgical MRI exceeded the 4-month period.

### Imaging protocol

All the examinations were performed with a 1.5-T scanner (Magnetom Symphony, Siemens AG, Erlangen, Germany), with a dedicated phased array coil. The protocol included turbo spin echo sequences (TSE), fat-suppressed, proton density or T2-weighted, in the axial, coronal and sagittal planes (TR 4820 ms, TE 12 or 71 ms, FOV 16 × 16 cm, matrix 384 × 288) and one TSE T1-weighted sequence in the sagittal or coronal plane (TR 600 ms, TE 12, FOV 16 × 16 cm, matrix 256 × 192). All images had a 3-mm slice thickness. The field of view included all the knee anatomy from the apex of the patella to the distal insertion of the patellar tendon.

### Arthroscopic criteria to determine tear reparability

The following criteria were considered to decide whether to perform meniscal repair or meniscectomy during arthroscopy. First, tears located within the red zone were considered reparable. Intraoperatively, this was evaluated using the 90°-bent tip of the arthroscopic probe, which is 5 mm long. Meniscal tears located from the external edge within the length of the tip were deemed suitable for repair. Second, tears with an intact inner fragment were considered reparable. Whenever appropriate, meniscal margins were regularized with debridement, and healing was enhanced by abrading the tissue with a rasp, but fragments with chronic degenerative changes were removed. Third, the tear type was taken into consideration. Vertical tears within the red zone were considered reparable. Radial and horizontal tears were deemed not reparable, except for complete radial tears and horizontal tears completely encompassing the red zone. Bucket-handle tears were deemed not reparable, except for tears in the acute stage with a viable displaced fragment and when the tear was located within the red zone all along its length. Complex tears or flaps were not repaired.

### MRI criteria to evaluate meniscal tears

We designed an algorithm to assess meniscal tears on MRIs and predict their reparability in consensus with three orthopedic surgeons (F.B., G.Z. and S.P., see Fig. 1). Two independent radiologists retrospectively reviewed all the MRIs and

provided predictions for each tear. The readers had respectively 4 and 25 years of experience in musculoskeletal imaging and were blinded to the name, age, original MRI report and surgical procedure performed on the patients.

Tears were grouped in six patterns: vertical, horizontal, radial, flaps, bucket handle and complex (Fig. 2). We considered a 5-mm cutoff value for the distance from the menisco-capsular junction to the tear. For any type of tear, first we searched for the presence of flaps because they would necessarily lead to partial meniscectomy. For the vertical tears, we measured the distance from the menisco-capsular junction to the edge of the tear on the tibial or femoral side (see Fig. 3) at different locations on the three orthogonal planes. We considered bucket-handle tears as vertical tears extending to the entire meniscus; they were given special attention because they can be repaired only if they are included in the red zone through their entire length. Vertical or bucket-handle tears were considered non-reparable if one of the distances measured on the MRIs was greater than or equal to 5 mm. Considering horizontal tears, measurements were done on the central sagittal and coronal planes to visualize orthogonal meniscus sections without partial volume effects (see Fig. 4). The measure was taken from the menisco-capsular junction to the edge of the tear on the tibial or the femoral surfaces; tears were considered non-reparable if at least one distance was greater than or equal to 5 mm. Partial radial tears, arising along the inner edge and extending toward the periphery, were predicted to undergo meniscectomy. Only complete radial tears were considered reparable. We considered those tears extending in more than one plane or with a patchy increase of the T2

signal within the meniscus substance as complex. These tears were deemed non-reparable.

Other parameters that were recorded in the database were the side (right or left), whether it was the medial meniscus or the lateral one and the concomitant presence of an anterior cruciate ligament (ACL) injury.

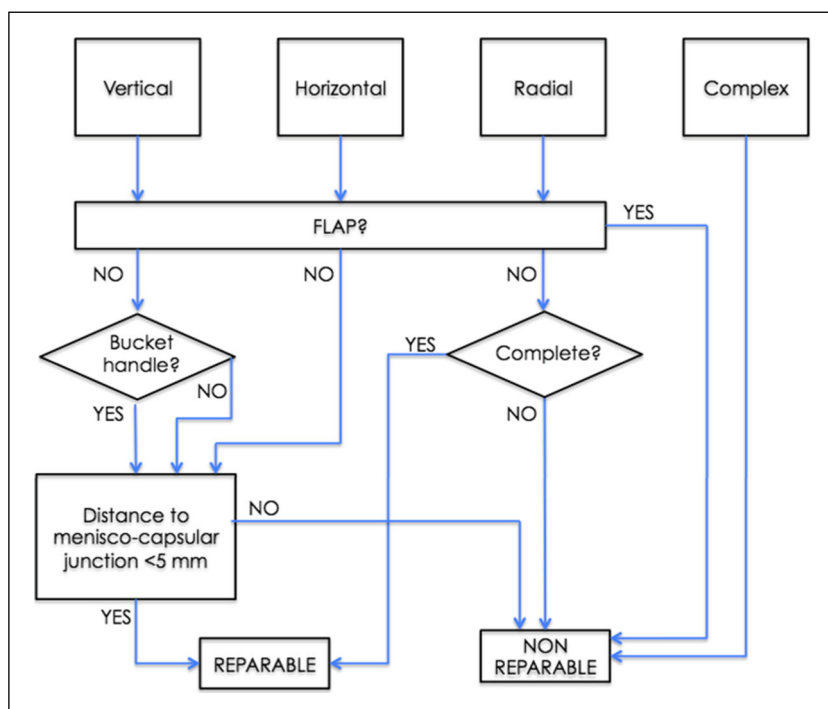
### Reference standard

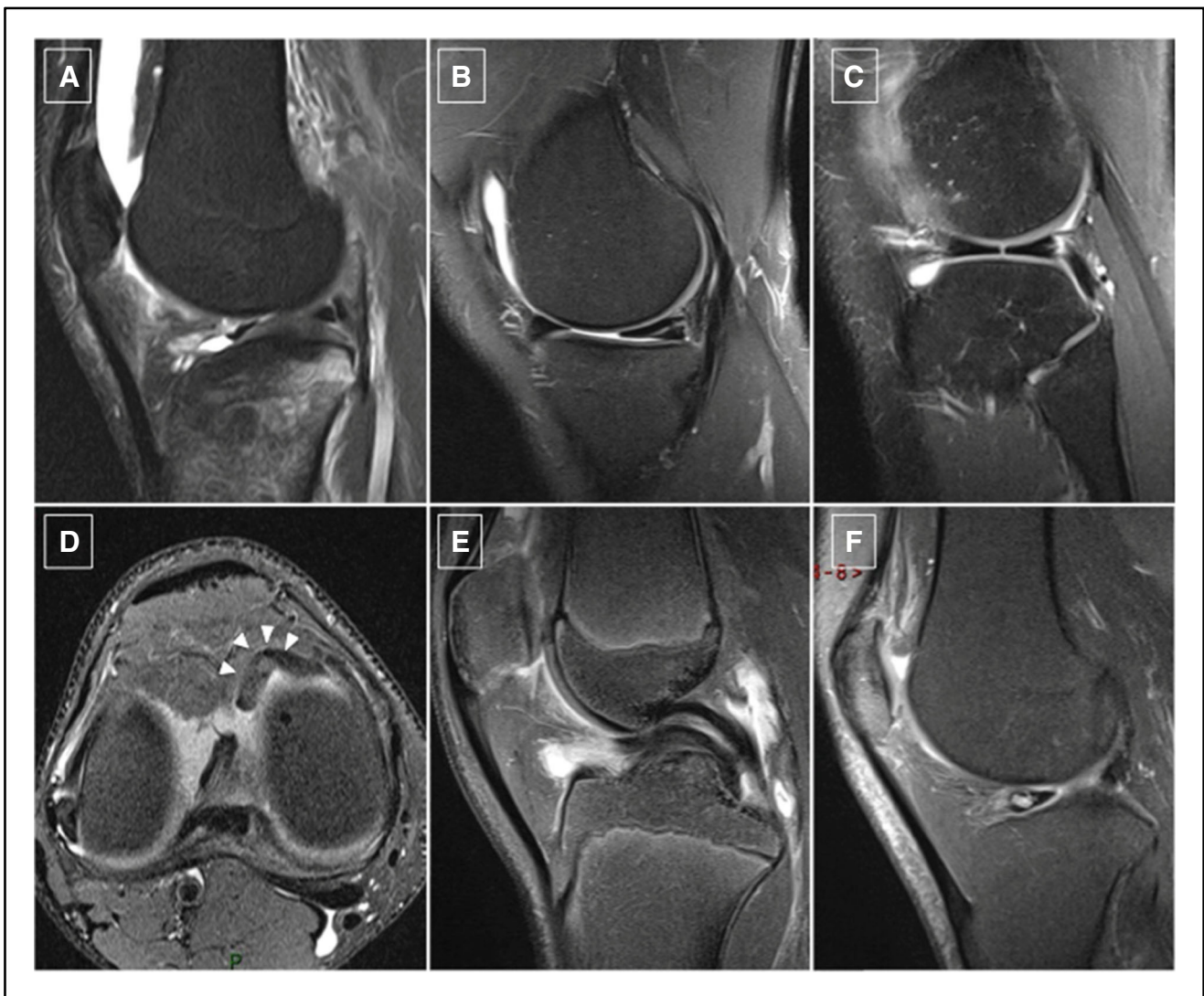
Our reference standard was the arthroscopic procedure performed against which the MRI predictions were compared. One single surgeon conducted all the procedures (G.Z.). All the subjects were operated on using “all inside” sutures with Fast-Fix devices (Smith and Nephew, Andover MA, USA).

### Statistical analysis

Unweighted Cohen’s *k* analysis [15] was used to assess the agreement between the readers’ predictions and the arthroscopic outcome and between the two readers (inter-rater agreement). The coefficient obtained was defined according to the guidelines of Landis and Koch [16] as follows: poor (<0.2), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80) and excellent (0.81–1.00). Values of sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy of MRI were calculated for both readers. Predictive rates for each specific subgroup of tears were calculated. Receiver-operating characteristic (ROC) curves were created using the menisco-capsular distance measured by the first reader as the continuous variable. This analysis included only the

**Fig. 1** Diagnostic algorithm to assess meniscal tears with MRI and predict tear reparability





**Fig. 2** Meniscal tear patterns. MRI of the knee, proton density weighting with fat suppression, sagittal and axial planes. **a** Longitudinal vertical tear at the posterior horn of the medial meniscus. **b** Longitudinal horizontal tear at the posterior horn of the medial meniscus. **c** Radial tear at the

central aspect of the body of the lateral meniscus. **d** Anteriorly displaced meniscal flap (arrowheads). **e** Bucket-handle tear with the classic double PCL sign. **f** Complex tear with a patchy increase of signal at the anterior horn of the lateral meniscus

vertical, horizontal and bucket-handle tears, since measurements were not taken for the other tear patterns. Then, ROC curves were plotted for subgroups of only-vertical tears (including pure vertical and bucket-handle) and only-horizontal tears. A multivariate logistic regression model was used to identify parameters associated with reparability.

A *p*-value of less than 0.05 was considered statistically significant. The statistical analysis was computed using the MedCalc software (MedCalc Software, Ostend, Belgium).

## Results

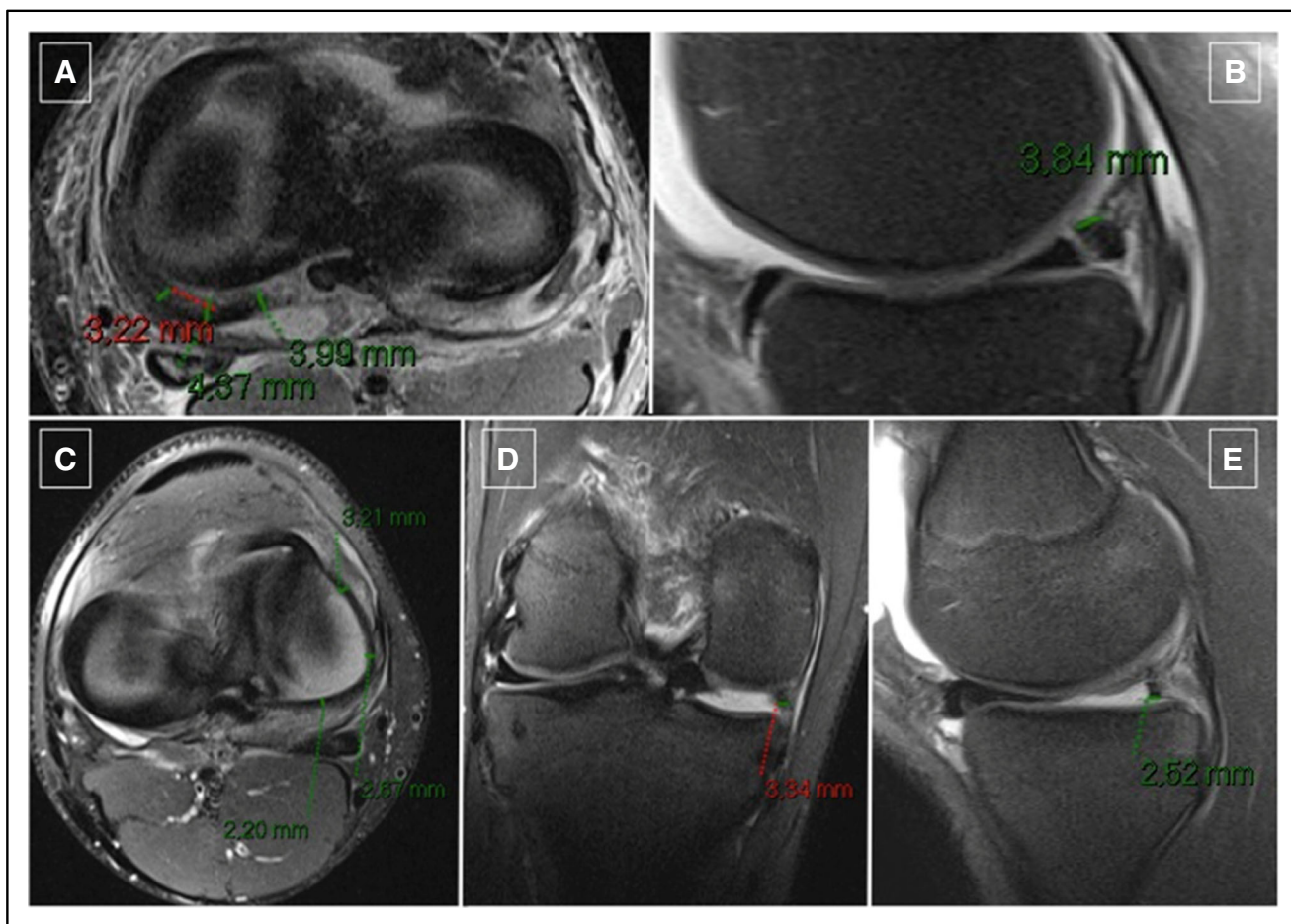
Thirty subjects fulfilled the inclusion criteria and were included in this study (20 males, 10 females; mean age  $27.2 \pm 9.7$

years, range 14–44). Forty-nine patients were included in the control group (39 males, 10 females, mean age  $28.4 \pm 8.8$  years, range 14–44).

Patients' demographics and the features of the meniscal tears are summarized in Table 1.

The agreement between the MRI predictions and arthroscopic procedures performed was good for both readers (reader 1:  $k = 0.65$ , standard error 0.09; CI 0.48–0.82; reader 2:  $k = 0.61$ , standard error 0.09, CI 0.43–0.92). Inter-rater agreement between the readers was almost excellent ( $k = 0.79$ ; standard error 0.07, CI 0.66–0.93).

Average MRI performance in predicting reparability was as follows: sensitivity 85%; specificity 79%; accuracy 83%. Positive and negative predictive values were respectively 87% and 76% (Table 2). The highest prediction rates were



**Fig. 3** Sample measurements of the distance from the menisco-capsular junction to the tear. MRI of the knee; proton density weighting with fat suppression. **a,b** Vertical tear of the posterior horn of the medial meniscus. The measure is taken from the menisco-sinovial junction to the peripheral rim of the tear. In the axial plane (**a**) the measure is repeated many times at different locations. In the sagittal plane, (**b**) the measure is taken at the orthogonal slice to the posterior horn to obtain a true section

of the meniscus and minimizing partial volume effects. **c,d,e** Bucket-handle tear of the medial meniscus. In this specific type of tear extending from the anterior to the posterior horn of the medial meniscus, the measure is taken at multiple locations in the axial (**a**) plane and at the orthogonal slices to the meniscus in the coronal (**b**) and sagittal (**c**) planes

obtained for bucket-handle tears (91% for reader 1, 81% for reader 2) and complex tears (86% for both readers) (see Table 3). Prediction rates for both readers were respectively 78% and 73% for vertical tears and 80% and 88% for horizontal tears. Reader 1 correctly predicted 3/4 (75%) of radial tears and reader 2 4/4 of them (100%). For complex tears, predictivity was 100% for reader 1 and 67% for reader 2.

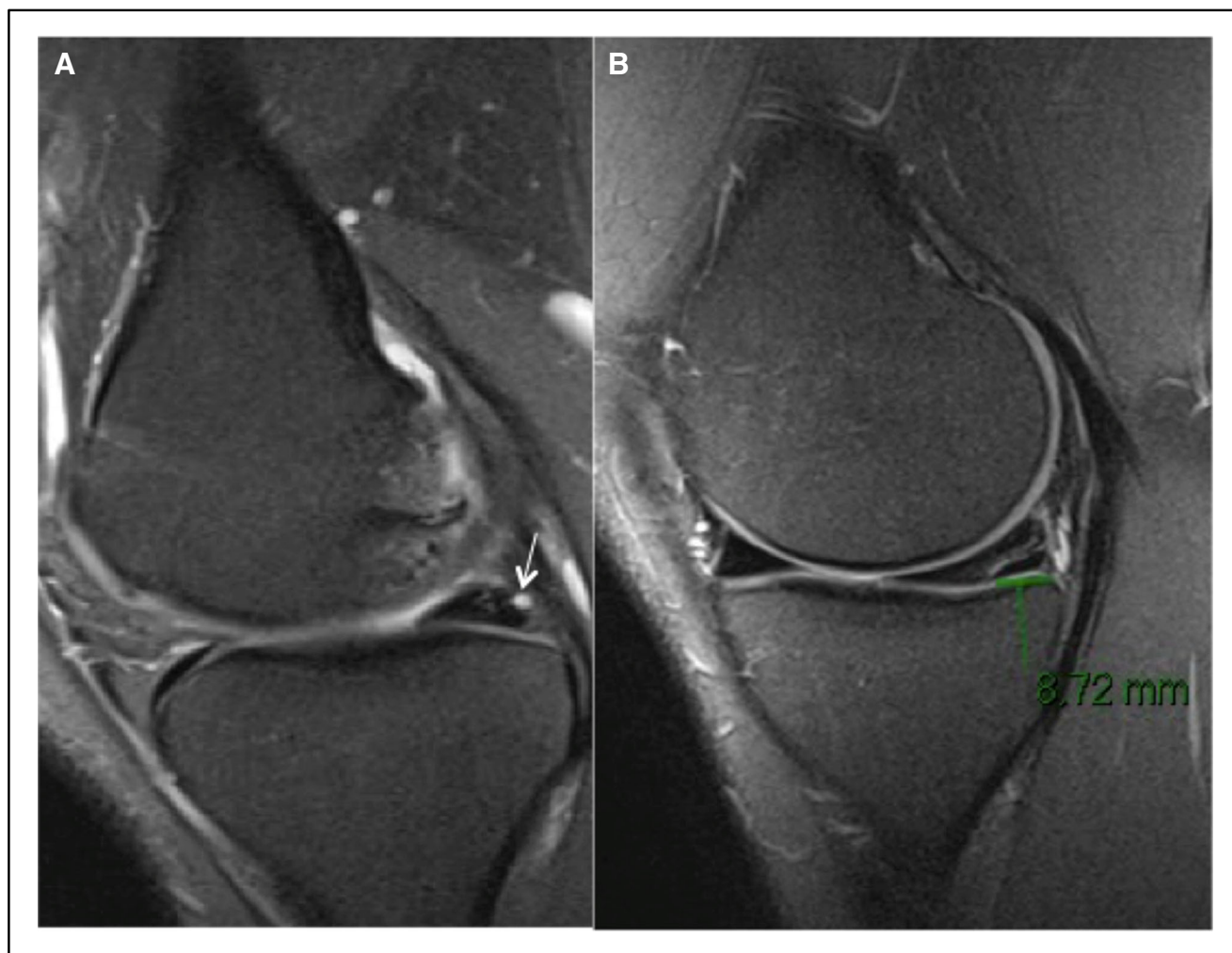
The ROC analysis revealed sensitivity values of 73% and specificity values of 83% with a cutoff value <4 mm of the menisco-capsular distance. The area under the curve (AUC) was 0.85 ( $p < 0.001$ ). The ROC analyses for only-vertical tears (including vertical and bucket-handle tears) revealed sensitivity of 70% and specificity of 90% with a cutoff value <3 mm (AUC 0.86,  $p < 0.001$ ) and for only-horizontal tears sensitivity values of 50% and specificity values of 85% with a cutoff value of <5 mm (AUC 0.76,  $p < 0.01$ ) (Fig. 5).

The multivariate logistic regression model showed that the presence of ACL injury increased the likelihood of

meniscal tear reparability and that the medial meniscus was more likely to be repaired than the lateral meniscus. Age was inversely proportional to reparability with borderline statistical significance ( $p = 0.06$ ). Sex and side of the tear were not significantly correlated with meniscal reparability in this model (Table 4).

## Discussion

The basic principles of meniscal surgery are minimal invasiveness and preservation of the normal meniscal tissue. Arthroscopy is now standard of care, and meniscal repair is the treatment of choice to preserve the integrity and mechanical function of the meniscus. However, not all tears are repairable. In non-repairable cases, partial meniscectomy is performed, removing the torn tissue and contouring the remaining meniscus to a stable peripheral rim. Tears located in the



**Fig. 4** Pitfalls. **a** Subject with no tear seen on the MRI; the arthroscopy performed 70 days later demonstrated a bucket-handle tear that was treated with partial meniscectomy. A small parameniscal cyst was found on a second look (arrow). Parameniscal cyst can be sentinel signs of horizontal tear. **b** Subject with a longitudinal horizontal tear repaired with

sutures; after 9 months, he underwent a surgical revision for a re-tear, leading to partial meniscectomy. At the MRI, the distance from the menisco-sinovial junction and the tear was >5 mm, thus according to our criteria the first repair was not appropriate

external third of the meniscus (the vascularized “red zone”) may heal successfully. Tears occurring in the transitional zone between the red zone and the non-vascularized zone (red-white zone) may also heal, but the decision to repair is based on surgical judgment, considering the patient’s age and patient’s request to continue intense athletic activity. Acute tears with smooth margins may adhere properly and facilitate healing, while chronic tears with irregular edges and degenerative changes have poor chances to heal. Both the surgeon and patient would benefit from a reliable predictor of tear reparability since meniscal repair is usually more strenuous and requires a longer recovery time and different rehabilitation programs.

In this study we have shown that MRI can be a powerful tool to predict meniscal tear reparability with accuracy values of 83%, sensitivity of 85% and specificity of 79%. Previous investigators found controversial results. Bernthal et al. [10]

showed an accuracy of 60%, with sensitivity and specificity respectively of 47% and 74% in predicting meniscal tear reparability. Matava et al. [11] demonstrated accuracy of 74%,

**Table 1** Population demographics and features of meniscal tears. (V: vertical, H: horizontal, R: radial, C: complex, ACL: anterior cruciate ligament)

	Meniscectomy ( <i>n</i> = 49)	Repair ( <i>n</i> = 30)
Age (years) mean	28.4 ± 8.8	27.2 ± 9.7
Sex (male)	39 (79%)	20 (50%)
Side (right)	30 (61%)	16 (53%)
Meniscus (medial)	35 (71%)	26 (90%)
Location (posterior horn)	36 (87%)	26 (90%)
Direction (V, H, R, C, F, B)	3, 20, 4, 6, 9, 7	19, 6, 0, 1, 0, 4
ACL injury	9 (18%)	24 (83%)

**Table 2** Performance of MRI in predicting meniscal tear reparability. Values are expressed in %. PPV; positive predictive value. NPV negative predictive value

	Sensitivity	Specificity	PPV	NPV	Accuracy
Reader 1	88	77	86	79	84
Reader 2	82	80	87	73	81
Average	85	79	87	76	83

sensitivity of 29% and specificity of 89% and suggested that MRI was only moderately reliable in predicting reparability. In patients with only bucket-handle and vertical tears, various studies [12, 14] found MRI accuracy of 93–94% in predicting meniscal tear reparability. Shiozaki et al. [13] reported accuracy values of 91% and sensitivity values of 33% in a population of only lateral meniscal tears.

To our knowledge, this is the first study to include an all-inclusive set of meniscal tears taking their pattern into consideration. As previously stated, this is a critical point since vertical tears are repaired more frequently than all the others, horizontal tears are less frequently repaired, and radial tears, flaps and complex tears usually undergo partial meniscectomy. This is confirmed by our results, since 19/22 (86%) of the vertical tears were repaired compared to only 6/26 (23%) of the horizontal ones; bucket-handle tears were repaired in 4/11 cases (36%); only 1/7 of the complex tears was repaired (14%); radial tears and flaps were all treated with partial meniscectomy (see Table 3).

We decided to use a single criterion, which was the distance from the menisco-capsular junction to the tear, without considering other criteria such as the length, the thickness of the tear or the assessment of the damaged fragment, which were used in previous studies instead. The reason is that we wanted to emphasize the role of the tear pattern and reduce the number of confounding variables, keeping the only criterion we believed to be crucial. In addition, the surgeon did not actually

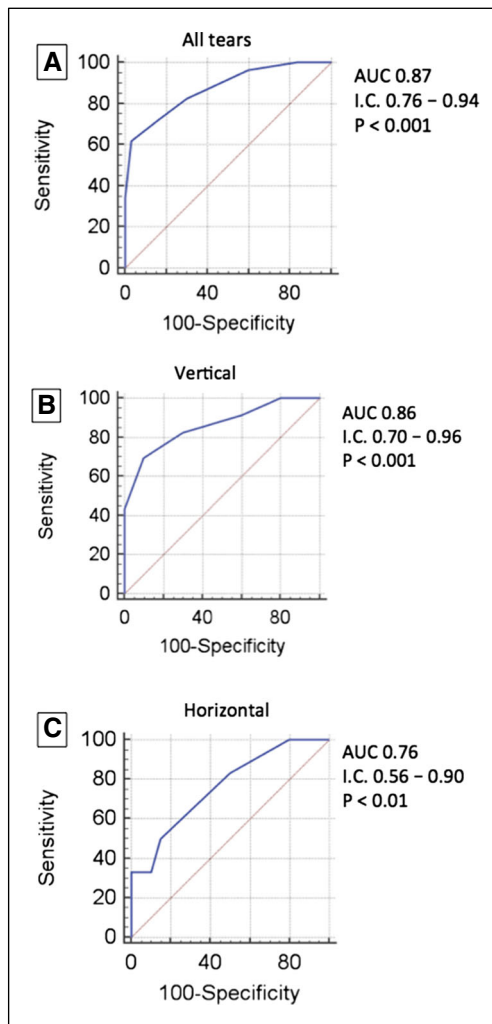
measure the tears at the arthroscopy; thus, the measurements were exclusively an MRI criterion. Some of the previous studies used a 3-mm cutoff [10, 11, 13], while others 4 mm [12, 14]. On the basis of preliminary data and personal experience, we decided to increase this cutoff to 5 mm. Eventually our ROC analysis revealed an optimal cutoff value of 4 mm with sensitivity of 73% and specificity of 83%, all tears included. When the ROC analysis was performed in the different tear subgroups, it revealed an optimal cutoff of 3 mm for vertical tears and of 5 mm for horizontal tears (Fig. 5).

One of the difficulties that we encountered in our preliminary tests was reliably taking the measurements. In most cases, the edges of the meniscal walls and tears were easily identified because we acquired high-resolution images. The readers were instructed to take multiple measurements of the tears at different locations of the meniscus on the three orthogonal planes. Those measurements were taken on the tibial or femoral surfaces of the meniscus from the outer edge of the tear, i.e., from the last dark pixel of the meniscus facing the bright pixels of the tear, to the meniscal wall. On the coronal and sagittal planes, measurements were taken only at the central slices where the meniscus section was exactly perpendicular to its main axis to avoid partial volume effects. If at least one of the measurements was >5 mm, the tear was considered non-reparable. These efforts were meant to reduce the variability in judgment between readers, and, in fact, our inter-rater agreement was almost excellent ( $k = 0.79$ ).

It is known that meniscal tears concurrent with ACL injury are more probably repaired because meniscectomy in unstable knees is associated with early osteoarthritis [17–19]. On the other hand, meniscectomy in stable knees, i.e., without ACL failure, is associated with good long-term results [20]. We also found the medial meniscus to be more frequently reparable than the lateral: some authors indicate possible better healing capacities of the lateral meniscus [21]; others did not find significant differences between the healing rates of lateral and medial menisci [4].

**Table 3** Performance of MRI in predicting specific types of meniscal tears. This table summarizes the arthroscopic outcomes for each group of tears and the correct predictions of reparability by the two readers

		Meniscectomy (n)	Repair (n)	Correct predictions		
				Reader 1	Reader 2	Mean
Total		49	30	66/79 (84%)	64/79 (81%)	83%
Meniscus	Medial	35	26	50/61 (82%)	50/61 (82%)	82%
	Lateral	14	4	16/18 (88%)	14/18 (78%)	83%
Type	Vertical	3	19	17/22 (78%)	16/22 (73%)	76%
	Horizontal	21	6	21/26 (80%)	23/26 (88%)	84%
	Radial	4	0	3/4 (75%)	4/4 (100%)	88%
	Complex	6	1	6/7 (86%)	6/7 (86%)	86%
	Flap	9	0	9/9 (100%)	6/9 (67%)	84%
	Bucket handle	7	4	10/11(91%)	9/11(81%)	86%



**Fig. 5** ROC (receiver operating characteristic) curves. Each curve illustrates the performance of the menisco-capsular junction to tear distance as a discriminator of tear reparability. **a** All tear patterns are considered; sensitivity values of 72% and specificity values of 83% are obtained with a cutoff value of <4 mm. **b** Only vertical tears; sensitivity values of 70% and specificity values of 90% are obtained with a cutoff value of <3 mm. **c** Only horizontal tears; sensitivity values of 50% and specificity values of 85% are obtained with a cutoff value of <5 mm. AUC: area under the curve. IC: confidence intervals

This study has several limitations. First, the readers reviewed the examinations only once, and therefore intra-observer reliability could not be calculated. Future studies can be performed to independently validate our results on a different sample of patients and to incorporate intra-reader reliability statistics. In addition, this is a retrospective study with a selected population of operated subjects only. Future prospective studies should test MRI before surgery, assessing the value of imaging in pre-surgical planning more precisely. We considered pre-surgical imaging performed at a maximum of 4 months before surgery, while previous authors considered a limit of 3 months. The meniscal status can change in both cases during this delay

**Table 4** Multivariate logistic regression model. This model is created with four independent variables. The presence of concomitant ACL injury and the medial side of the tears were positively correlated with reparability. Regarding the distance from the tear to the menisco-capsular junction, the odds of repair decrease by a factor of 2.5 (= 1/0.4) for every mm increase in distance. Age is negatively related to reparability with borderline statistical significance ( $p = 0.06$ )

Variable	Odds ratio	95% CI	p
Medial meniscus	13.5910	1.6294 to 113.3657	0.0159
ACL repair	11.8782	2.6401 to 53.4420	0.0013
Distance	0.4000	0.2475 to 0.6465	0.0002
Age	0.9159	0.8357 to 1.0039	0.0605

time. It certainly occurred in one case where both readers detected no tears but the surgeon found a bucket-handle tear, treated with meniscectomy. The delay between MRI and arthroscopy was 70 days. Another limitation is that only one surgeon performed the meniscal repairs. This may be a peculiarity of our orthopedic surgery department; in other hospitals there could be less uniformity in the surgeon practice. We only had a partial follow-up of the patients who underwent surgery that we did not include in the present study. We are aware that re-tear occurred in only one case of a repaired meniscus. This subject had a horizontal tear located more than 6 mm from the menisco-capsular junction (Fig. 4); according to our criteria, this case was not repairable. Finally, all examinations were conducted with a 1.5-T scanner. The spatial resolution of the images is a critical point for precise evaluation of the tear orientation, type and measurements. We used a dedicated multichannel coil and an optimized and standardized protocol to obtain the highest resolution in all planes; however, in many hospitals 3-T scanners are increasingly available and may generate higher resolution images that could provide additional valuable information to clinicians.

## Conclusion

Using the correct criteria, magnetic resonance imaging can be a powerful diagnostic tool for predicting meniscal tear reparability when the tear pattern is considered. Radial tears, flaps and complex tears have poor chances to be repaired. Presurgical MRI showed a sensitivity of 85% and specificity of 79% in predicting vertical, horizontal and bucket-handle tear reparability when located a maximum of 5 mm from the menisco-capsular junction. Preoperative MRI can provide the surgeon information about the location, pattern and extent of a meniscal tear and predict which type of surgery should be performed with an improvement of surgical management and patient expectations with good accuracy.



## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

## References

- Kim S, Bosque J, Meehan JP, Jamali A, Marder R. Increase in outpatient knee arthroscopy in the United States: a comparison of national surveys of ambulatory surgery, 1996 and 2006. *J Bone Jt Surg Am* [Internet]. 2011;93:994–1000. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21531866>
- Shybut T, Strauss EJ. Surgical management of meniscal tears. *Bull NYU Hosp Jt Dis* [Internet]. 2011;69:56–62. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21332440>
- Arnoczky SP, Warren RF. Microvasculature of the human meniscus. *Am J Sport Med* [Internet]. 1982;10:90–5. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/7081532>
- Bach BR Jr, Dennis M, Balin J, Hayden J. Arthroscopic meniscal repair: analysis of treatment failures. *J Knee Surg* [Internet]. 2005;18:278–84. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16262009>
- Starke C, Kopf S, Petersen W, Becker R. Meniscal repair. *Arthroscopy* [Internet]. 2009;25:1033–44. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/19732643>
- Noble J. Lesions of the menisci. Autopsy incidence in adults less than fifty-five years old. *J Bone Jt Surg Am* [Internet]. 1977;59:480–3. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/577209>
- Lee SJ, Aadalen KJ, Malaviya P, et al. Tibiofemoral contact mechanics after serial medial meniscectomies in the human cadaveric knee. *Am J Sport. Med* [Internet]. 2006;34:1334–44. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16636354>
- Mesiha M, Zurakowski D, Soriano J, Nielson JH, Zarins B, Murray MM. Pathologic characteristics of the torn human meniscus. *Am J Sport. Med* [Internet]. 2007;35:103–12. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17092929>
- Behairy NH, Dorgham MA, Khaled SA. Accuracy of routine magnetic resonance imaging in meniscal and ligamentous injuries of the knee: comparison with arthroscopy. *Int Orthop*. 2009;33:961–7.
- Bernthal NM, Seeger LL, Motamedi K, et al. Can the reparability of meniscal tears be predicted with magnetic resonance imaging? *Am J Sport. Med* [Internet]. 2011;39:506–10. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21173193>
- Matava MJ, Eck K, Totty W, Wright RW, Shively RA. Magnetic resonance imaging as a tool to predict meniscal reparability. *Am J Sport. Med* [Internet]. 1999;27:436–43. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/10424212>
- Nourissat G, Beaufils P, Charrois O, et al. Magnetic resonance imaging as a tool to predict reparability of longitudinal full-thickness meniscus lesions. *Knee Surg Sport Traumatol Arthrosc* [Internet]. 2008;16:482–6. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/18292991>
- Shiozaki Y, Horibe S, Mitsuoka T, Nakamura N, Toritsuka Y, Shino K. Prediction of reparability of isolated semilunar lateral meniscus tears by magnetic resonance imaging. *Knee Surg Sport. Traumatol Arthrosc* [Internet]. 2002;10:213–7. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/12172713>
- Thoreux P, Rety F, Nourissat G, et al. Bucket-handle meniscal lesions: magnetic resonance imaging criteria for reparability. *Arthroscopy* [Internet]. 2006;22:954–61. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/16952724>
- Cohen J. A coefficient of agreement for nominal scales. *Educ Psychol Meas*. 1960;20:37–46.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* [Internet]. 1977;33:159–74. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/843571>
- Hutchinson ID, Moran CJ, Potter HG, Warren RF, Rodeo SA. Restoration of the meniscus: form and function. *Am J Sport. Med* [Internet]. 2014;42:987–98. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/23940202>
- Beaufils P, Hulet C, Dhenain M, Nizard R, Nourissat G, Pujol N. Clinical practice guidelines for the management of meniscal lesions and isolated lesions of the anterior cruciate ligament of the knee in adults. *Orthop Traumatol Surg Res* [Internet]. 2009;95:437–42. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/19747891>
- Melton JT, Murray JR, Karim A, Pandit H, Wandless F, Thomas NP. Meniscal repair in anterior cruciate ligament reconstruction: a long-term outcome study. *Knee Surg Sport. Traumatol Arthrosc* [Internet]. 2011;19:1729–34. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21479642>
- Yoo JC, Ahn JH, Lee SH, Lee SH, Kim JH. Suturing complete radial tears of the lateral meniscus. *Arthroscopy* [Internet]. 2007;23:1249 e1–7. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/17986421>
- Cannon WD Jr, Vittori JM. The incidence of healing in arthroscopic meniscal repairs in anterior cruciate ligament-reconstructed knees versus stable knees. *Am J Sport. Med* [Internet]. 1992;20:176–81. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/1558246>