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Varus knee osteoarthritis: how can we identify ACL insufficiency?

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Abstract

Purpose The aim of this prospective study was to determine the clinical value of lateral radiographs and corresponding MRI scans in the preoperative evaluation of the functional integrity of the anterior cruciate ligament (ACL) in a consecutive series of 78 patients (93 knees) with medial compartment osteoarthritis.

Methods All knees received standardised radiographs and MRI imagery. The wear pattern on the lateral radiograph was described based on a modified Keyes classification. On MRI, the ACL and the percentage of intact posterior cartilage in relation to the anteroposterior tibia width were assessed.

Results The MRI showed an intact ACL in 23 (25 %) knees, evidence of ACL degeneration in 54 (58 %) knees and a complete ACL tear in 16 (17 %) knees. All knees with an intact ACL showed ≥14 % intact posterior cartilage on sagittal MRI scans, except for one knee. All knees with a torn ACL demonstrated <14 % intact posterior cartilage. Of the 54 knees with evidence of ACL degeneration, eight knees had <14 % intact posterior cartilage similar to the wear pattern present in knees with torn ACLs. Out of the 24 knees with a torn or degenerated ACL and <14 % intact posterior cartilage on MRI, 23 (96 %) knees demonstrated posterior bony erosion on corresponding lateral radiographs.

Conclusions The assessment of intact posterior tibial cartilage on MRI and lateral radiographs helps to identify knees with functional ACL insufficiency. MRI with assessment of both the ACL morphology and the underlying tibial wear pattern appears to provide additional clinical benefit in cases in which the extent of posterior bony erosion on the lateral radiograph cannot be assessed with confidence.

Level of evidence Diagnostic study, Level II.

Keywords ACL · Function · Insufficiency · Degeneration · Cartilage wear pattern · MRI · Lateral radiographs

Introduction

The preoperative assessment of overall alignment [9, 21], ligament stability [1], and location and size of cartilage damage [15] in end-stage knee osteoarthritis (OA) is crucial for the selection of patients for unicompartmental versus total knee replacement (TKR). In patients with medial compartment knee OA, the functional integrity of the anterior cruciate ligament (ACL) is considered an essential requirement for unicompartmental knee replacement (UKR) [3]. Higher failure rates have been reported for UKR in patients with an insufficient ACL at the time of surgery [2], and therefore, most authors consider a medial UKR only in patients with an intact ACL and anteromedial tibial cartilage wear [18]. The entity of anteromedial OA has first been described by White et al. [22]. Several further studies have suggested an association between the radiographic [8] or intraoperative [17] tibial wear pattern and the

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functional integrity of the ACL. In cases with an intact ACL, the tibial wear appears to be limited to the anteromedial tibial plateau, whereas it increases in size and progresses further posteriorly in cases with an insufficient or torn ACL as a result of underlying instability in the sagittal plane [13, 17, 22]. In patients with medial compartment OA, it has been postulated that the presence of posterior tibial bony erosion on the preoperative lateral radiograph is a good indicator for identifying functionally insufficient ACLs [7, 8, 13, 14, 23].

Based on the current literature, the clinical value of radiographs and MRI [19] in the preoperative assessment of the functional status of the ACL is not clearly understood, and no clear cut-off levels have been defined. We therefore asked the following research questions: (1) Does the structural appearance of the ACL on MRI predict the location of tibial cartilage wear on MRI and lateral radiographs? (2) Can we identify cut-off levels for the posterior tibial cartilage wear on MRI to identify ACL insufficiency? (3) Does a modified Keyes (mKeyes) classification of the lateral radiograph correlate with the MRI cartilage wear pattern?

Materials and methods

In a prospective consecutive series, 100 knees in 84 patients who underwent primary TKR for end-stage varus knee OA between May 2010 and January 2012 were studied. Each patient received a preoperative standardised hip-to-ankle AP standing radiograph, an AP standing knee radiograph, a lateral knee radiograph and a magnetic resonance imaging (MRI) of the knee. Intraoperatively, the ACL was macroscopically graded by the senior author as intact or torn.

The exclusion criteria included (1) secondary OA and (2) neutral or valgus alignment of the knee on the hip-to-ankle AP standing radiographs. Patients were prospectively enrolled in this study. Seven knees were retrospectively excluded because not all radiographs were on file, leaving 93 knees (46 right knees and 47 left knees) in 78 patients (35 male, 43 female). The mean age was 67 years (range 49–87) with a mean BMI of 25.6 kg/m^2 (range 17.4–46.8).

Radiographic and MRI protocols

All radiographs were obtained following standardised institutional protocols. On hip-to-ankle AP standing radiographs, the crosshair of the X-ray beam was centred between the knees and on AP standing radiographs on the patella, respectively. For lateral radiographs, the patient was positioned on the side with approximately 30° of flexion, thereby placing the outer side of the knee directly on the film.

All subjects underwent MRI using 1.5 or 3T clinical scanners (GE Healthcare, Waukesha, WI) using either an eight-channel phased array receive only cardiac coil (Invivo, Orlando, FL), a quadrature receive only lower extremity coil (Invivo, Orlando, FL) or a three-channel phased array receive only shoulder coil (USA Instruments Inc., Aurora, OH). Two-dimensional fast spin echo images were obtained in three planes. For those exams performed at 1.5 T, the repetition time (TR) was 4,000–5,000 ms, echo time (TE) of 34–40 ms, field of view (FOV) of 140 (axial) to 160 (sagittal) mm, matrix of 512 × 384, slice thickness of 3.5–4 mm with no gap. For those exams performed at 3.0 T, the TR was 5,100–5,300 ms, TE of 30 ms, FOV of 140 (axial) to 160 (sagittal) mm, matrix of 512 × 416, slice thickens of 3.5–4 mm with no gap.

The grading and measurements of all radiographs was performed on a picture archiving and communication system (PACS) with commercial planning software (Sectra IDS7, Sectra, Linköping, Sweden).

Radiographic and MRI assessment

The radiographic assessment according to the Kellgren and Lawrence (KL) grading scale [6] was performed on AP standing radiographs for the medial compartment.

A modified Keyes grading scale was used to evaluate the functional integrity of the ACL on lateral radiographs (Tables 1, 2). In knees with an intact ACL, the tibial wear appears to be limited to the anteromedial tibial plateau, whereas the erosion progresses further posteriorly in cases with an insufficient or torn ACL as a result of underlying instability in the sagittal plane.

The original Keyes classification [8] suggests a combined assessment of medial compartment OA on varus stress radiographs and lateral radiographs. Grade 1 and grade 2 of the original Keyes classification only describe the degree of anteromedial OA on AP varus stress

Table 1 Radiographic assessment of the anterior cruciate ligament (*ACL*): The original Keyes classification [8] requires an AP varus stress radiograph and a lateral radiograph to assess the integrity of the ACL

Original Keyes classification		
Grade	AP varus stress radiograph	Lateral radiograph
1	Reduction in joint space	
2	Obliteration of joint space	
3	Tibial plateau erosion <5 mm	Posterior part of plateau intact
4	Erosion 5–10 mm	Erosion extends to posterior margin of the plateau
5	Severe subluxation of the tibia	Erosion subluxation of the tibia >10 mm

Table 2 The mKeyes classification focuses only on the degree of posterior tibial bony erosion on lateral radiographs to evaluate sagittal instability

Modified Keyes classification	
Grade	Lateral radiograph
1	Intact posterior tibial plateau
2	Erosion extends to the posterior margin of the plateau
3	Erosion extends to the posterior margin with subluxation of the tibia

radiographs and do not facilitate the assessment of the ACL. Grade 1 and 2 were, therefore, excluded and, a modified Keyes classification (mKeyes) was used (Table 2).

On hip-to-ankle AP standing radiographs, the hip-knee-ankle angle (HKAA) was defined as the angle between the femoral mechanical axis (centre of hip [11] to centre of knee [10]) and the tibial mechanical axis (centre of knee [10] to centre of ankle [12]).

On MRI, the sagittal T1-weighted image demonstrating the greatest anteroposterior extent of the full-thickness cartilage defect on the medial tibial plateau was selected. The distance from the anterior margin to the posterior margin of the bony tibial plateau (L_{PLA}), the length of the cartilage defect (L_{DEF}), the length of the remaining intact anterior cartilage (L_{ANT}) and the length of the remaining intact posterior cartilage (L_{POST}) were measured in millimetres with an accuracy of one decimal. The length of the full-thickness cartilage defect (L_{DEF}) and the length of the intact anterior and posterior full-thickness cartilage (L_{ANT}, L_{POST}) were expressed as percentage of the total length of the tibia plateau (L_{PLA}) (Fig. 1). On MRI, the structural integrity of the ACL was graded as intact (ACL-0), with degenerative changes (ACL-1) and completely torn (ACL-2) [4]. The group of ACLs with degenerative changes included thinning, scarring, ganglion formation, mucoid degeneration or partial tears of the ACL as previously reported [20]. The assessment of all ACLs was based on the report of a blinded board-certified radiologist with extensive experience in musculoskeletal MRI.

The study was approved by the Hospital for Special Surgery Institutional Review Board (#29023) and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All patients gave informed consent prior to inclusion in the study.

Statistical analysis

For descriptive analysis, absolute mean values of HKAA were expressed in degrees with 95 % confidence intervals (CIs). L_{DEF}, L_{ANT} and L_{POST} were expressed in per cent with 95 % CIs. The Kolmogorov–Smirnov test was performed to test for normal distribution of variables. As not all variables met the criteria for normal distribution, the Mann–Whitney *U* test or the Kruskal–Wallis test was used to compare the distribution of variables. p values <0.05 were considered significant. Intra- and interobserver reliabilities for measurements on hip-to-ankle radiographs, and MRIs were assessed by two independent blinded observers (WW, JBM) for 20 randomly selected corresponding samples. Intra- and interobserver reliabilities for the grading on AP standing and lateral radiographs were evaluated by two independent blinded observers (WW, FB) for all radiographs. For intraobserver reliabilities, grading and measurements were performed at two occasions separated by a minimum of 4 weeks. A two-way mixed model with 95 % CIs was used for the calculation of intraclass correlation coefficients (ICC). Statistical tests were carried out using SPSS 17 software for windows (SPSS Inc., Chicago, Illinois).

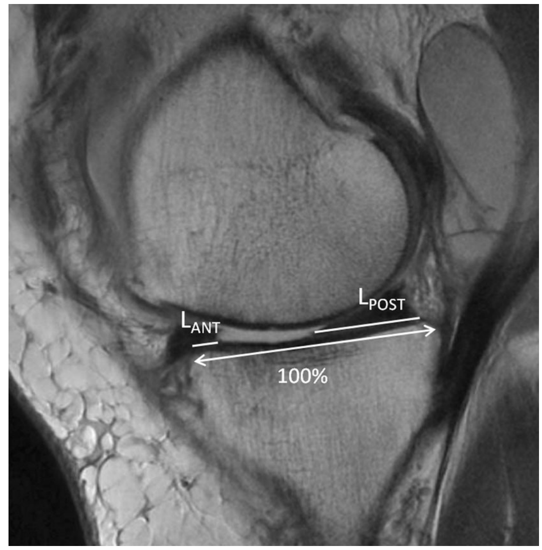

Fig. 1 Sagittal T1-weighted image demonstrating the greatest anteroposterior extent of the full-thickness cartilage defect on the medial tibial plateau. The distance from the anterior margin to the posterior margin of the bony tibial plateau represents 100 %. Measurements of intact anterior (L_{ANT}) and posterior (L_{POST}) cartilage are displayed. The length of the intact posterior cartilage was 40 % in this 67-year-old woman

Results

Excellent intra- and interobserver ICC were seen for all parameters analysed (Table 3).

On AP standing radiographs, the medial compartment was graded as KL 3 in 20 knees (21.5 %) and KL 4 in 73 knees (78.5 %). On hip-to-ankle AP standing radiographs, mean varus alignment was 8.5° (95 % CI 7.7–9.4). The assessment of posterior bony erosion on lateral radiographs showed no erosion (mKeyes grade 1) in 69 knees (74 %), posterior erosion (mKeyes grade 2) in 22 knees (24 %) and tibial subluxation in two knees (2 %), respectively. All knees ($n = 24$) with posterior bony erosion (mKeyes grade 2 and 3) on lateral radiographs also showed marked medial plateau erosion on AP standing radiographs.

On MRI, 23 (25 %) of the ACLs were intact, 54 (58 %) showed degenerative changes and 16 (17 %) had a complete tear. The L_{DEF} of the medial tibial plateau increased significantly ($p < 0.001$) with increasing degeneration of the ACL. There was no significant difference ($p = 0.483$) in the length of intact anterior cartilage (L_{ANT}) for knees with intact ACLs, ACLs with degenerative changes and torn ACLs. The length of intact posterior cartilage significantly ($p < 0.001$) decreased with increasing grades of ACL degeneration (Fig. 1; Table 4).

In all knees with an intact ACL, L_{POST} was ≥14 %, except for one knee that had L_{POST} of 0 % and marked posterior erosion on the lateral radiograph. Of the 54 knees with degenerative changes in the ACL, 46 knees (85 %) displayed a L_{POST} of ≥14 % on MRI and a mKeyes grade 1 on lateral radiographs. In eight knees (15 %) with degenerative changes in the ACL, L_{POST} was <14 %, and in all these knees, there was posterior bony erosion (mKeyes grade 2) on lateral radiographs. All 16 knees with a torn ACL on MRI had posterior cartilage of <14 %. In these 16 knees, the lateral radiographs demonstrated posterior bony erosion, except for one knee. In total, 25 knees presented with posterior full-thickness cartilage of <14 %, suggestive of a functionally insufficient ACL (Figs. 2, 3; Table 5).

Table 3 Interobserver and intraobserver ICC for analysed parameters

Parameter	Interobserver ICC	Intraobserver ICC
KL-medial ($n = 93$)	0.810	0.948
mKeyes ($n = 93$)	0.937	0.949
HKAA ($n = 20$)	0.996	0.999
L_{PLA} ($n = 20$)	0.978	0.954
L_{DEF} ($n = 20$)	0.985	0.902
L_{ANT} ($n = 20$)	0.850	0.932
L_{POST} ($n = 20$)	0.994	0.950

ICC intraclass correlation coefficient, *HKAA* hip-knee-ankle angle

The percentage of intact posterior cartilage (L_{POST}) was 22.7 % (95 % CI 21.2–24.3) in patients with grade 1 according to the mKeyes classification on lateral radiographs, 5.8 % (95 % CI 3.4–8.1) in knees with grade 2 and 0 % in knees with grade 3, respectively (Fig. 4).

The intraoperative assessment of the ACL demonstrated eight completely torn ACLs which were all detected as torn ACLs using preoperative MRI. However, eight additional ACLs did not show a complete tear intraoperatively but were classified as torn on MRI.

Discussion

The most important finding of the present study was that patients with a torn ACL showed a significantly longer tibial cartilage defect (L_{DEF}) in the sagittal plane and had significantly less intact posterior tibial cartilage ($L_{POST} < 14$ %) than patients with a structurally intact ACL. There was a good correlation between the MRI findings and the evaluation of the wear pattern on lateral radiographs.

All knees with posterior bony erosion on lateral radiographs showed bone on bone OA in the medial compartment on AP standing radiographs. Therefore, the use of varus stress radiographs as originally suggested by Keyes et al. [8] (Table 1) does not appear to be of any clinical relevance in identifying ACL deficient knees, and the authors suggest a mKeyes classification based only on the lateral knee radiograph (Table 2).

Table 5 Agreement of ACL status and posterior tibial cartilage (L_{POST}) on MRI, and posterior bony erosion on lateral radiographs for the entire cohort

MRI		Lateral radiograph		
ACL Status	L_{POST} (%)	No erosion (grade 1)	Posterior erosion (grade 2)	Tibial subluxation (grade 3)
Intact	≥14	22	0	0
	<14	0	1	0
Degenerative changes	≥14	46	0	0
	<14	0	8	0
Torn	≥14	0	0	0
	<14	1	13	2

Table 4 Mean L_{DEF} and mean length of intact posterior cartilage (L_{POST}) for knees with intact ACLs, ACLs with degenerative changes and torn ACLs for the entire cohort

ACL status (%)	MRI		
	Intact	Degenerative changes	Torn
L_{DEF}	38.2 (95 % CI 32.5–43.8)	45.6 (95 % CI 42.2–49.0)	62.8 (95 % CI 53.5–72.0)
L_{POST}	22.3 (95 % CI 18.7–25.9)	20.5 (95 % CI 18.5–22.6)	4.8 (95 % CI 0.9–8.3)

Only one patient showed marked posterior bony erosion and posterior cartilage defect on the corresponding lateral radiograph and MRI despite an intact ACL both intraoperatively and on MRI; the patient presented status post arthroscopic posterior horn meniscectomy in 1991, and the findings might be secondary to post-operative cartilage damage. A second patient was assessed with a completely torn ACL based on MRI and also the intraoperative assessment but did not show any evidence of posterior erosion on the lateral radiograph; however, on corresponding MRI scans, a marked tibial defect with <14 % of intact posterior cartilage was noted in this case. This finding confirms the high sensitivity of MRI for identifying a functionally deficient ACL when the posterior cartilage wear pattern is taken into consideration.

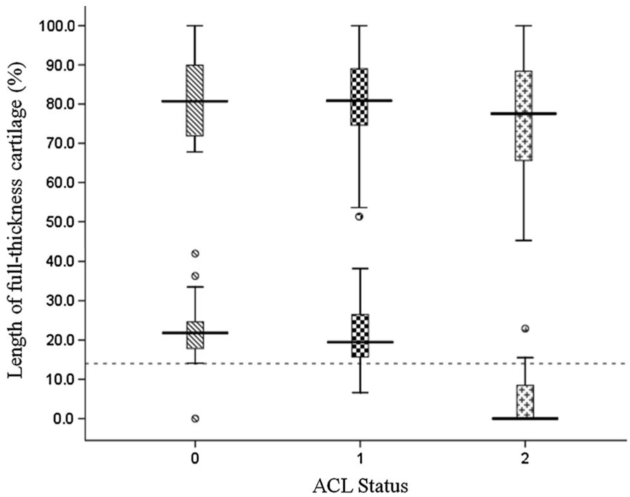

Fig. 2 Boxplot demonstrating the anterior border (*top*) and posterior border (*bottom*) of the full-thickness cartilage defect in per cent of AP width of the tibia plateau for knees with intact ACLs (0), degenerative ACL changes (1) and complete tears (2) on MRI. 100 % represent the anterior margin of the tibia plateau, 0 % the posterior margin, respectively. The reference line at 14 % of posterior cartilage on MRI suggests a cut-off for the functional status of the ACL in the present cohort

MRI scans of the majority of cases (58 %) showed at least some morphological alterations of the ACL, whereas in only 17 % of cases, the ACL was classified as completely torn. To our knowledge, there are two other studies that have investigated the role of MRI in the preoperative assessment of the ACL [5, 19]. Sharpe et al. [19] reported that 33 % of patients with anteromedial OA showed signs of ACL degeneration on MRI compared to only 13 % on surgical inspection, and the authors suggested that MRI is too sensitive in the detection of morphological ACLs alterations to be of much practical value in identifying suitable candidates for UKR. Our findings suggest that adding measurements of the per cent of intact posterior cartilage might be more important than

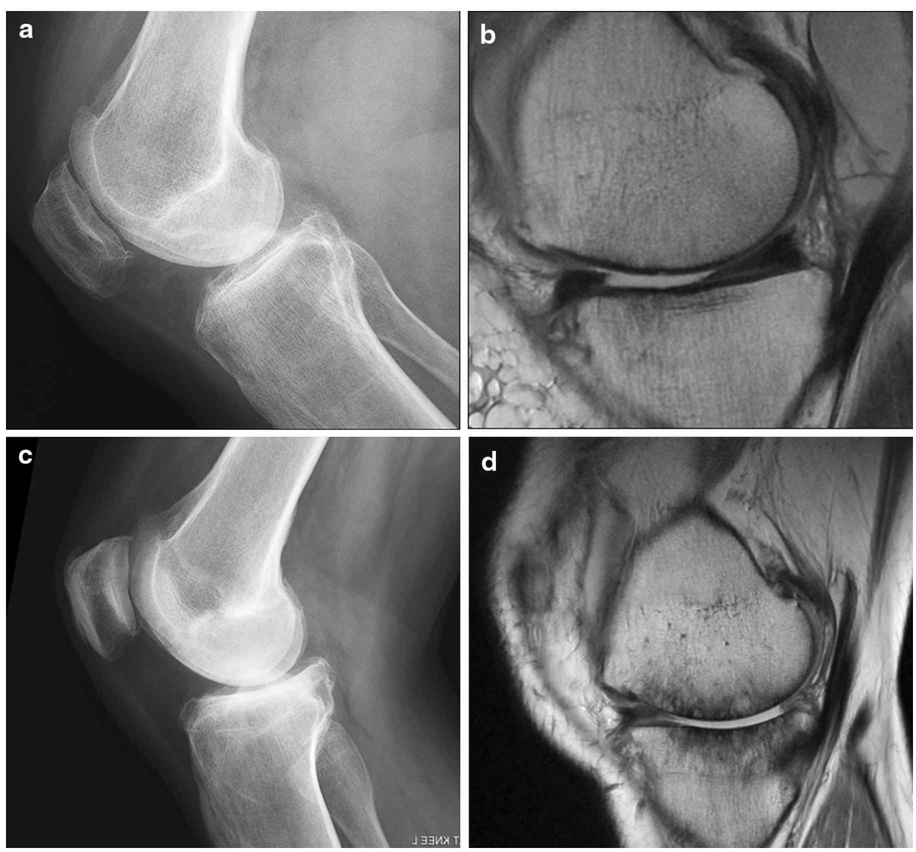

Fig. 3 Demonstration of high agreement between tibial wear patterns on preoperative lateral radiographs and corresponding MRI scans. Lateral radiograph (**a**) with no posterior bony erosion (mKeyes grade 1) with an intact ACL and 44 % of posterior intact cartilage on corresponding MRI (**b**). Lateral radiograph (**c**) with posterior bony erosion (mKeyes grade 2) with a degenerated but not torn ACL and marked posterior cartilage defect on corresponding MRI (**d**)

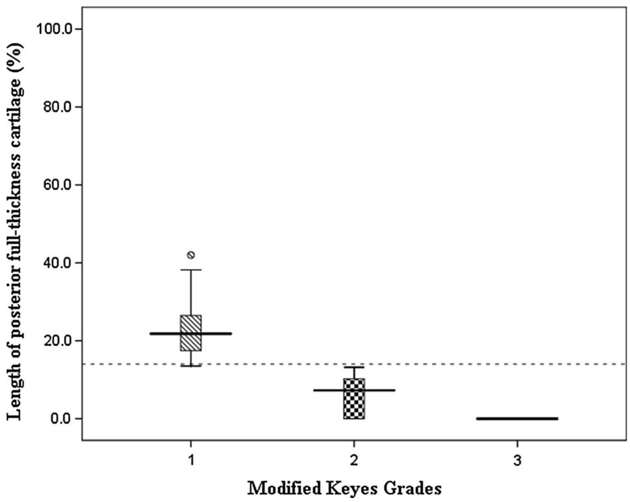

Fig. 4 Boxplot demonstrating the length of posterior full-thickness cartilage (%) on MRI for knees with no posterior bony erosion (grade 1), posterior erosion (grade 2) and subluxation (grade 3) on lateral radiographs for the entire cohort. The reference line at 14 % of posterior cartilage on MRI suggests a cut-off for the functional status of the ACL in the present cohort

the morphologic description of the ACL. Isolated evaluation of the ACL on MRI may be misleading as it may not give an adequate impression of the functional ACL status. Johnson et al. [5] recently performed MRI scans on a subgroup of their patients scheduled for TKR. The authors classified wear as anterior, posterior and central. In the posterior wear type, wear is seen in the posterior 50 % of the tibia, in the anterior type, wear is seen in the anterior 50 %, and in the central type, there is no bias to anterior or posterior observed. The report concluded that analysis of tibial cartilage wear patterns were not useful in the diagnosis of ACL integrity. The current study does not support those findings. Our results show that tibial wear always begins in the anterior part of tibia and with increasing ACL degeneration the defect progresses posteriorly in sagittal plane. There was no difference in the anterior borders of the defect between any of the ACL groups. It is, therefore, recommended measuring the percentage of intact posterior tibial cartilage to define the wear pattern.

The present study has the following limitations: A blinded intraoperative evaluation of the ACL was performed; however, there is no objective or standardised method for intraoperative ACL assessment, and hence, the authors believe that subjective macroscopic assessment is potentially prone to misinterpretation and can, therefore, not be considered as a gold standard of the assessment of the ACL. In the literature, intraoperative findings of ACL alteration in knee OA are of descriptive nature and have demonstrated a high variability ranging from synovial defects, bulking to longitudinal splits and partial tears [8, 13, 17]. Thus, structural intraoperative ACL assessment poses the risk of accepting a functionally deficient ACL as satisfactory for UKR or bicruciate-retaining TKR which may result in the development of abnormal kinematic patterns [16] potentially leading to early failure of the implant [2]. For all MRI measurements, the sagittal MRI scan demonstrating the greatest anteroposterior extent of the full-thickness cartilage defect on the medial tibial plateau was selected. We decided not to take measurements through the mid-point of the medial tibia plateau or the section showing the greatest AP width of the tibia which might be more consistent. Since, depending on alignment, the presence of a lateral thrust or mediolateral stability the cartilage defect can be more medial and might not be perfectly visualised in the centre of the medial tibia plateau. However, we believe that choosing the slice with the greatest anteroposterior extent of the full-thickness cartilage defect best reflects the mechanical effects of the ACL deficiency. The intraobserver and interobserver reliability for all MRI-based measurements was excellent.

In clinical practise, the amount of intact posterior cartilage on MRI should be considered for evaluating the functional integrity of the ACL, especially in knees with degenerative ACL changes. According to the present study, the radiographic assessment of wear patterns on lateral radiographs (mKeyes classification), as well as the assessment of the percentage of intact posterior cartilage (L_{POST}) on MRI both appear to be excellent tools to assess the functional status of the ACL. In the current paper, a cut-off level of $\geq$14 % posterior full-thickness tibia plateau cartilage is proposed to identify knees with a functionally intact ACL.

Conclusion

The percentage of intact posterior cartilage on the medial tibia plateau should be included in the assessment of the ACL on MRI imaging to identify patients with wear patterns suggestive of a functionally insufficient ACL as intraoperative assessment does not identify all patients with ACL insufficiency. MRI with assessment of both the ACL morphology and the underlying tibial wear pattern appears to provide additional clinical benefit in cases in which the extent of posterior erosion on the lateral radiograph cannot be assessed with confidence.

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

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