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Unicompartmental versus bicompartmental joint space width measures: Which reflect whole joint structural damage better? Data from IMI-APPROACH

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ABSTRACT

Objective: To investigate the associations between whole joint cartilage and meniscal morphology on MRI and radiographic joint space width (JSW) measures and in knee osteoarthritis (KOA), to determine whether bicompartmental measures demonstrate stronger associations than unicompartmental ones, and to evaluate their correlations with Kellgren and Lawrence grading.
Design: A cross-sectional analysis of baseline radiographs and MRIs from 262 KOA participants in the prospective, multicenter IMI-APPROACH cohort was conducted. Radiographic measures included minimum joint space width (mJSW), fixed location JSW (JSW(x)), mean JSW, and joint line convergence angle (JLCA), assessed using fully automated software. JSW was evaluated both unicompartmentally and bicompartmentally. Cartilage morphology, full-thickness cartilage loss, meniscal extrusion, tears, and maceration were assessed using the semi-quantitative MRI Osteoarthritis Knee Score to summarize whole-

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joint cartilage and meniscal morphology. Associations of radiographic measures with MRI outcomes were assessed using multivariable linear regression; Spearman correlations with Kellgren and Lawrence (KL) were also evaluated.
Results: MRI-defined meniscal maceration was associated with unicompartmental and bicompartmental JSW measures. Full-thickness cartilage loss was associated with unicompartmental (95% CI [-0.16;-0.02]) and bicompartmental mJSW (95% CI [-0.14;-0.02]), and JLCA (95% CI [0.04;0.22]). Models explained 32–39% of variance for unicompartmental and 23–45% for bicompartmental measures (R^2). Bicompartmental measures showed stronger correlations with KL grading than unicompartmental measures (95% CI: −0.31 to −0.02).
Conclusions: Associations between whole-joint cartilage and meniscal degeneration are similar for uni- and bicompartmental JSW, with bicompartmental JSW showing stronger correlations with KL grades. These findings support including both compartments in radiographic assessment to improve structural evaluation in KOA.

Introduction

For radiographic assessment of knee osteoarthritis (KOA), key parameters include joint space width (JSW), Kellgren and Lawrence (KL) grading, and joint line convergence angle (JLCA). JSW is often the primary outcome in clinical trials and a common inclusion criterion in OA cohort studies [1,2]. JSW can be measured as minimum JSW (mJSW), fixed location JSW (JSW(x)), or mean JSW [3]. These JSW measures are typically applied unicompartmentally, most often the medial compartment, or are used without specifying the compartment [2,3].

Since KOA is considered a whole joint disease, assessing both the medial and lateral compartments provides a more accurate representation of disease progression. The KL grading system offers a joint-wide score based mainly on osteophytes and joint space narrowing, but its categorical nature limits sensitivity to subtle changes [4], and may have lower reproducibility Therefore, continuous variables, such as JSW and JLCA, offer an alternative to superiorly assess progression. The JSW can be expressed as a bicompartmental average, considering both the medial and lateral compartments. The JLCA is defined as the angle between the femoral and tibial joint lines [5]. It reflects cartilage loss, meniscal damage, and extrusion within one compartment relative to the contralateral compartment [5].

Despite the widespread use of these measures, the relationship between unicompartmental JSW and whole joint cartilage and meniscal morphology remains unclear, and the potential of bicompartmental measures is insufficiently explored. Because of the higher prevalence of medial compartment OA, most observational cohorts and clinical trials have focused primarily on the medial tibiofemoral compartment [6,7], and the majority of published studies restrict JSW measurement to this location [3,8,9]. Furthermore, it is common practice to compare such unicompartmental JSW measures with the whole-joint KL score [3,10,11]. To address these gaps, this study investigates three key research questions. First, we assess the cross-sectional correlation between whole joint cartilage and meniscal morphology assessed on MRI-scans and unicompartmental JSW; second, we examine whether bicompartmental measures yield stronger associations than unicompartmental ones; third, we evaluate the correlations of uni- and bicompartmental JSW measures with KL grading We hypothesized that whole-joint cartilage and meniscal morphology would be more strongly associated with bicompartmental JSW measures than with unicompartmental measures, and that bicompartmental JSW would show stronger correlations with KL grading compared to unicompartmental JSW.

Methods

Participants

In the prospective Applied Public-Private Research enabling OsteoArthritis Clinical Headway (IMI-APPROACH) cohort, 297 participants with femorotibial OA were included in five European centers and followed for 2 years [1].Recruitment was based on the clinical criteria from the American College of Rheumatology (ACR) and predictive models using radiographs, demographic, and clinical data from the screening visit to identify OA patients most likely to experience pain or structural progression over two-years [1,12]. Additional inclusion criteria included the ability to walk unassisted, primarily tibiofemoral KOA, and meeting the ACR clinical classification criteria for KOA [1]. At baseline, participants had weight-bearing radiographs and MRI of the index knee. Those without baseline radiographs or MRI were excluded in this study.

The study was approved by Institutional Review Boards, followed ethical and legal guidelines, including Good Clinical Practice and the Declaration of Helsinki. It was registered (NCT03883568), and all participants gave informed consent.

Imaging assessment

Radiographic imaging assessment

The radiographs were obtained following the Buckland-Wright protocol, with a posteroanterior view of the knee in semi-flexed position (7° - 10°) and under weight-bearing conditions [13,14]. Standard exposure parameters were applied (55 kV, 5 mAs) with a focal film distance of 1.2 m, the knee positioned against the detector, and the feet fixed in 7.5° external rotation. All radiographs were evaluated using the KL grading system by a blinded rheumatologist trained for KL scoring without specific prior experience. For four patients (1.5%), the baseline KL grade from this observer was unavailable; given the high inter-observer reliability (quadratic weighted kappa = 0.9), the corresponding KL grades from the second trained observer were used, resulting in a complete dataset. In addition, all knee radiographs were automatically analyzed using Orthopedic Digital Image Analysis (ODIA) [15] software to determine the mJSW, JSW(x), mean JSW, and JLCA in the medial and lateral compartments (Fig. 1). ODIA calculates mean JSW by fitting 30 intra-articular circles within the joint, with circle diameters representing JSW per compartment [15]. The smallest diameter per compartment defined the medial and lateral mJSW [15], while JSW(x) was measured at 0.275 (medial) and 0.725 (lateral) along the joint line, where 0 represents the most medial and 1 the most lateral point [8]. For unicompartmental measures, the medial compartment was used; bicompartmental values were calculated as the average of medial and lateral JSW. JLCA was defined as the angle between the distal femoral and proximal tibial joint lines [15], with neutral ranging from 0°–2°, varus as ≥2°, and valgus as ≤0° [16].

Magnetic resonance imaging assessment

MRI of the index knee was performed across five participating clinical sites. Two centers utilized 1.5 Tesla scanners (A Coruña: Ingenia CX, Philips Medical Systems, Netherlands; Oslo: Aera,

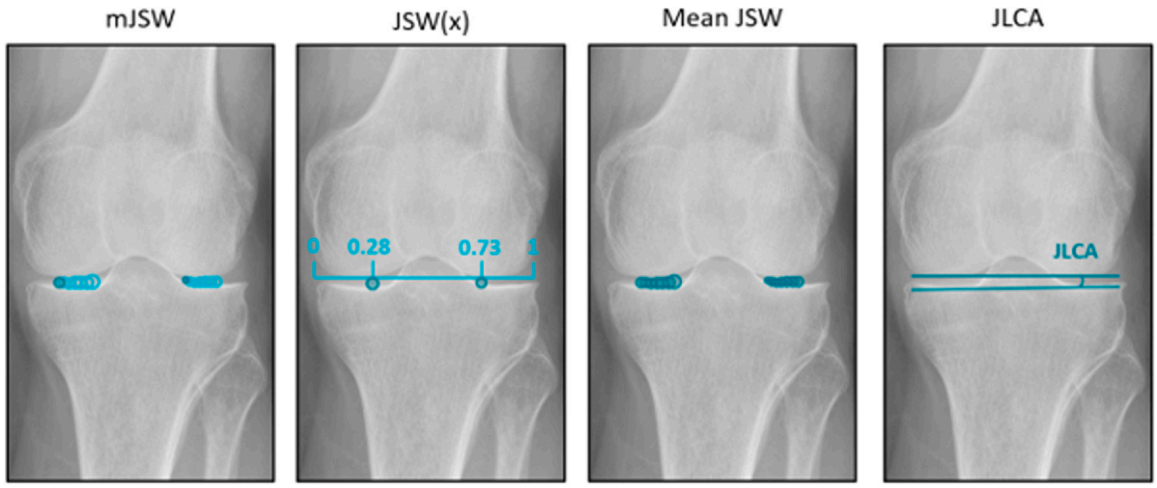

Fig. 1 Osteoarthritis and Cartilage

Radiographic Imaging Assessment. Measurements include the mJSW in the medial and lateral compartments, the fixed joint space width (JSW(x)), the mean JSW, and the joint line convergence angle (JLCA).

Siemens Healthcare, Germany), while the remaining three centers employed 3 Tesla systems (Utrecht: Ingenia or Achieva, Philips Medical Systems, Netherlands; Leiden: Ingenia, Philips Medical Systems, Netherlands; Paris: Skyra, Siemens Healthcare, Germany). The standardized imaging protocol included axial, sagittal, and coronal intermediate-weighted fat-suppressed sequences, along with a coronal T1-weighted turbo spin-echo sequence, all of which were applied for semi-quantitative assessment. All MRI examinations were performed without contrast administration. Whole joint cartilage and meniscal morphology was assessed using the semi-quantitative MRI Osteoarthritis Knee Score (MOAKS) [17], scored by an experienced radiologist with 17 years of experience at the time of reading, who was blinded to clinical data. The whole joint health evaluation included cartilage morphology, meniscal extrusion, and tears.

Cartilage morphology. Cartilage loss was categorized based on a real extent of partial cartilage loss and on percentage of full-thickness cartilage loss within that subregion (Fig. 2A and 2B). Area extent involvement was graded from 0 to 3 (< 10%, 10–75%, > 75%) and full-thickness cartilage loss represents the percentage of complete loss in a given subregion and was also graded from 0 to 3 [17]. Grading was performed in femoral (posterior, central) and tibial (anterior, central, posterior) subregions of both compartments. Whole joint cartilage loss was defined as the sum of scores across 10 subregions, ranging from 0 to 30. The same method was applied to full-thickness cartilage loss.

Meniscal extrusion. Whole joint meniscal extrusion was calculated as the sum of medial extrusion of the medial meniscus and lateral extrusion of the lateral meniscus (Fig. 2C). Each extrusion was graded from 0 to 3: Grade 0: < 2 mm, Grade 1: 2–2.9 mm, Grade 2: 3–4.9 mm, and Grade 3: > 5 mm [17]. The total score ranged from 0 to 6.

Meniscal tears. Meniscal tears were assessed in the anterior horn, body, and posterior horn of both the medial and lateral meniscus [17]. Grade 0 indicated an intact meniscus, while Grades 2–4 reflected varying tear types, and Grades 6–8 indicated different degrees of maceration (Fig. 2D). Patients were categorized into any tear (yes/no), and any maceration (yes/no).

Statistical analysis

All statistical analyses were performed using SPSS Version 29.0. Descriptive statistics (means, SD, frequencies, percentages) were calculated. Multivariable linear regression examined the association of partial cartilage loss, full-thickness cartilage loss, meniscal extrusion, and tears (independent variable) with unicompartmental and bicompartmental JSW measures and JLCA (dependent variables). Standardized beta coefficients were reported, representing the change in the outcome per 1 standard deviation increase in the exposure. Diagnostic checks were performed for all linear regression models. Normality of residuals was assessed using QQ plots, homoscedasticity was evaluated via plots of standardized residuals versus standardized predicted values, and multicollinearity was checked with VIF (< 5 for all predictors). Spearman's rho (ρ) correlations assessed the relationships between KL grading, unicompartmental and bicompartmental JSW measures, and JLCA (Fig. 1), with the absolute JLCA value used. Statistical tests (Steiger's Z-test) were used to compare the significance of correlations sharing one variable in common (KL-grading), with Z_H representing the test statistic for the difference between dependent correlations. A p-value < 0.05 was considered statistically significant.

In addition, sensitivity analyses were conducted to evaluate the robustness of the findings. Two models were specified: Model 1 included full-thickness cartilage loss, partial cartilage loss, meniscal extrusion, horizontal meniscal tear, vertical meniscal tear, complex meniscal tear, and meniscal maceration; Model 2 additionally adjusted for age, gender, weight, and height.

Results

Participants

Of the 297 participants in the IMI-APPROACH cohort, 262 participants were included with the required baseline data. The average age was 66.6 ± 7.2 years, and most participants were female (76.7%).

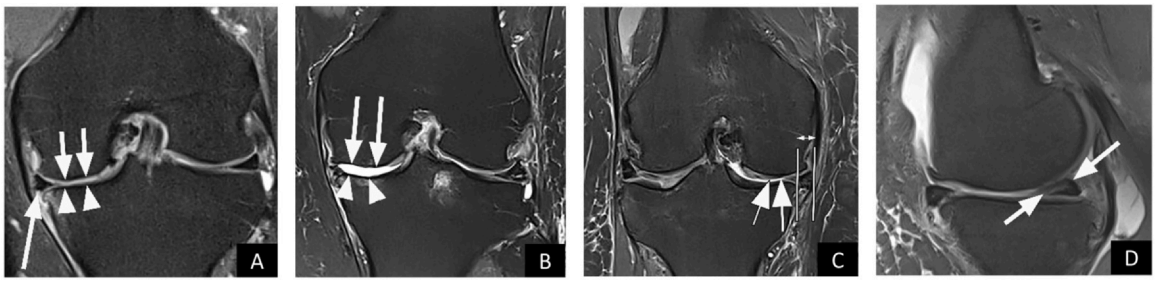

Fig. 2

Osteoarthritis and Cartilage

MOAKS assessment of MRI features contributing to joint space width and narrowing. A. Coronal intermediate-weighted fat suppressed 3 T MRI shows diffuse superficial cartilage damage in the central subregion of the medial femur (short arrows) corresponding to grade 3.0 MOAKS. In addition, there is wide-spread superficial thinning (grade 3.0) of cartilage at the central subregion of the medial tibia (arrowheads). There is grade 1 extrusion of the medial meniscus (long arrow). B. Another coronal image obtained at a 3 T system shows wide-spread full thickness cartilage loss (MOAKS grade 3.3) at the central medial femur (arrows) and tibia (arrowheads). C. Coronal MRI acquired at 3 T shows a grade 3 extrusion of the medial meniscus protruding 6 mm medially of the edge of the medial tibial plateau (vertical lines and double-headed arrow). In addition, there is superficial cartilage damage (MOAKS 2.0) at the central subregion of the medial femur. D. Sagittal intermediate-weighted fat suppressed MRI obtained at 1.5 T shows a classic degenerative horizontal-oblique tear of the posterior horn of the medial meniscus (arrows).

A detailed description of the participants can be found in Appendix A.

Association of MRI whole joint cartilage and meniscal morphology with unicompartmental JSW measures

MRI-defined full-thickness cartilage loss was associated with mJSW (beta = −0.29, 95% CI [-0.16;-0.02]). Partial cartilage loss, meniscal extrusion, and meniscal tears were not associated with mJSW, JSW(x), and mean JSW.

Meniscal maceration was associated with a reduction of mJSW (beta = −0.33, 95% CI [−1.29;−0.48]), JSW(X) (beta = −0.23, 95% CI [−1.03;−0.20], and mean JSW (beta = −0.27, 95% CI [−1.10;−0.31]). The models explained 22%, 13%, and 15% of the variance for mJSW, JSW (x), and mean JSW, respectively (R^2 values). These results are shown in Table 1.The results of the sensitivity analyses are presented in Appendix C.

Association of MRI whole joint cartilage and meniscal morphology with bicompartmental JSW measures and JLCA

Full-thickness cartilage loss was associated with bicompartmental mJSW (beta = −0.26, 95% CI [-0.14;-0.02]) and JLCA beta = 0.29, 95% CI [-0.4;0.22]). Partial cartilage loss, meniscal extrusion, and meniscal tears were not associated with average mJSW, average JSW(x), average mean JSW, and JLCA. Meniscal maceration was associated with a reduction of average mJSW (beta = −4.19, 95% CI [−1.00;−0.36]), average JSW(X) (beta = −0.25, 95% CI [−0.84;−0.23], average mean JSW (beta = −0.26, 95% CI [−1.00;−0.28]), and JLCA (beta = 0.23, 95% CI [0.31;1.32]).The models explained 25%, 34%, 25%, and 23% of the variance for bicompartmental JLCA, mJSW, JSW(x), and mean JSW, respectively (R^2 values), which seems higher than for unicompartmental measures. Results are summarized in Table 1. The results of the sensitivity analyses are presented in Appendix C.

Correlation with Kellgren and Lawrence score

The unicompartmental JSW measures (mJSW, JSW(X), mean JSW) showed weak correlations with KL grading, with Spearman's $\rho = -0.3$ (95% CI: −0.44 to −0.21 for mJSW; −0.40 to −0.17 for JSW(X); −0.40 to −0.18 for mean JSW). Bicompartmental JSW measures were also correlated with KL grading, with ρ values of −0.5 (95% CI: −0.54 to −0.35) for average mJSW, −0.4 (95% CI: −0.48 to −0.27) for average JSW(X), and −0.4 (95% CI: −0.47 to −0.25) for average mean JSW. The JLCA showed a moderate correlation with KL (ρ = 0.5, 95% CI: 0.35–0.55).

Bicompartmental JSW measures showed stronger correlations with KL grading than the corresponding unicompartmental measures (mJSW: $Z_H = -5.6$, 95% CI [-0.31;-0.16]; JSW(X): $Z_H = -2.7$, 95% CI [-0.19;-0.04]; mean JSW: $Z_H = -2.24$, 95% CI [-0.21;-0.02]). JLCA was more strongly correlated with KL grading than all unicompartmental JSW measures (Z_H = 3.3, 95% CI [0.11;0.36]). These results, including confidence intervals and the KL 2–4 subanalysis, are summarized in Appendix B.

Discussion

This study examined whether unicompartmental JSW measures were associated with MRI-assessed whole joint cartilage and meniscal morphology and if bicompartmental measures show stronger associations. Bicompartmental measures show similar associations with advanced structural damage, including full-thickness cartilage loss, partial cartilage loss, meniscal extrusion, tears, and maceration, as unicompartmental measures. Bi-compartmental JSW showed stronger correlations with KL grades than unicompartmental JSW, indicating that bicompartmental measures may better reflect overall radiographic disease severity. The absence of association with partial cartilage loss suggests that JSW measures primarily reflect more severe cartilage degeneration rather than diffuse joint changes. Moreover, the lack of associations with meniscal extrusion and meniscal tears indicates that JSW predominantly reflects meniscal maceration rather than extrusion or tears. Taken together, these findings support the use of bicompartmental measures as more sensitive indicators of joint structural damage in radiographic assessment.

Our findings also showed that full-thickness cartilage loss had a higher regression coefficient with JSW measures than partial cartilage loss. While cartilage loss includes both partial and full-thickness loss, full-thickness loss refers to complete cartilage loss within a specific subregion. Although prior research indicated that both partial and full-thickness cartilage defects contribute to the development of KOA [18], no previous studies have clearly shown that

	mJSW	JSW(x)	Mean JSW	JLCA
Unicompartmental				
Full-thickness cartilage loss	β = −0.26 **[-0.16;-0.02]***	β = −0.17 [-0.13;0.02]	β = −0.21 [-0.14;0.00]	
Partial cartilage loss	β = 0.08 [-0.04;0.08]	β = −0.06 [-0.08;0.05]	β = −0.01 [-0.05;0.06]	
Meniscal extrusion	β = 0.02 [-0.14;0.19]	β = 0.08 [-0.09;0.25]	β = −0.06 [-0.11;0.22]	
Meniscal tears	β = 0.01 [-0.27;0.34]	β = 0.08 [-0.11;0.51]	β = 0.04 [-0.20;0.39]	
Meniscal maceration	β = −0.33 **[-1.29;-0.48]***	β = −0.23 **[-1.03;-0.20]***	β = −0.27 **[-1.10;-0.31]***	
R^2	22%	13%	15%	
Bicompartmental				
Full-thickness cartilage loss	β = −0.26 **[-0.14;-0.02]***	β = −0.16 [-0.10;0.10]	β = −0.15 [-0.11;0.02]	β = 0.29 **[0.04;0.22]***
Partial cartilage loss	β = −0.10 [-0.07;0.02]	β = −0.18 [-0.08;0.01]	β = −0.16 [-0.09;0.02]	β = −0.05 [-0.09;0.06]
Meniscal extrusion	β = −0.00 [-0.13;0.13]	β = 0.04 [-0.09;0.15]	β = 0.04 [-0.11;0.18]	β = 0.10 [-0.08;0.33]
Meniscal tears	β = −0.00 [-0.23;0.25]	β = −0.00 [-0.23;0.23]	β = 0.05 [-0.16;0.38]	β = 0.01 [-0.35;0.42]
Meniscal maceration	β = −0.29 **[-1.00;-0.36]***	β = −0.25 **[-0.84;-0.23]***	β = −0.26 **[-1.00;-0.28]***	β = 0.23 **[0.31;1.32]***
R^2	34%	25%	23%	25%

mJSW, minimum joint space width; JSW(x), fixed location joint space width; JSW, joint space width; JLCA, Joint Line Convergence Angle

Table 1

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Associations between radiographic measures and whole joint health on MRI. The table presents regression coefficients (β), confidence intervals, and explained variance (R^2) for each radiographic parameter. The R^2 values indicate the proportion of variance in each radiographic measure explained by the set of MRI-assessed MOAKS parameters included in the model. Unicompartmental (medial compartment) and bicompartmental joint space width (JSW) measures, as well as joint line convergence angle (JLCA), were analyzed in relation to MRI-assessed full-thickness cartilage loss, partial cartilage loss, meniscal extrusion, and meniscal tears, and meniscal maceration. Significant associations are indicated with an asterisk (*).

full-thickness cartilage loss has a stronger association with JSW than partial cartilage loss. This emphasizes that full-thickness loss is fundamentally different from superficial cartilage loss, a distinction that is not fully captured by commonly used measures such as average cartilage thickness or cartilage volume. Therefore, including full-thickness loss, for example quantified as denuded bone area, as a continuous measure is important to more accurately reflect its effect on JSW.

Additionally, meniscal maceration showed higher regression coefficient with JSW than meniscal extrusion or tears. The sensitivity analysis, in which distinctions were made according to tear type, did not result in higher R-squared values. Notably, the contribution of meniscal extrusion to JLCA also appeared to be higher than that of other bicompartmental measures. This finding can be explained by the more frequent medial extrusion of the medial meniscus compared to lateral extrusion of the lateral meniscus in the IMI-APPROACH [19]. The same trend of more involvement of the medial meniscus was observed for anterior extrusion. Since JLCA reflects the angle between the distal femur and proximal tibia [15,16], this usually asymmetrical meniscal extrusion likely explains its stronger association with JLCA compared to other bicompartmental JSW measures.

Our study highlights the importance of evaluating both the medial and lateral compartments in radiographic assessments of KOA. When focusing on a single compartment, it is essential to explicitly report the compartment from which JSW measurements are derived—a detail that is frequently omitted in the literature [20,21]. The reliability of JSW measurements has improved with computerized analysis [22]; however, the smallest detectable difference (SDD) ranges between 0.5–1.5 mm with semi-automated methods [4] but decreases to 0.30–0.68 mm with fully automated software [15]. The JLCA, although not yet widely included as a radiographic measure in KOA assessments, showed stronger correlations with KL grading than unicompartmental JSW measures. JLCA is relatively simple to measure manually and has shown high inter- and intra-observer reliability [23], with a SDD of 0.48° [15]. In addition, it does not require radiograph calibration.

This study has several limitations. First, the cross-sectional design limits conclusions on KOA progression, longitudinal studies are needed to assess the added value of bicompartmental measures. Second, measurement and positional errors in JSW may have influenced results [24]. We used fully automated software, which is reproducible, but minor inaccuracies in landmark detection may still occur [4]. Third, we selected specific cartilage and meniscal parameters from the MOAKS. Including additional parameters may enhance the associations observed and offer a more comprehensive assessment of whole joint health. Fourth, simultaneous medial narrowing and lateral widening may offset each other, potentially obscuring true changes in bicompartmental JSW measures. Fifth, in this study we focused on mJSW, mean JSW, and JSW(X) as our JSW measures. However, a previous publication by Cheung *et al.* [25] concluded that measurement of multiple JSWs across the tibial plateau yields superior predictive performance for KOA compared with mJSW. This multiple JSWs measure was not included in this study, although the mean JSW can be considered a measure of JSWs across the tibial plateau. Finally, in this study we focused on the MOAKS score as a measure of whole-joint cartilage and meniscal morphology. However, for future research it would be valuable to also include T2 mapping in order to draw conclusions whether changes in compositional measures of cartilage may have an impact on radiographic JSW measures longitudinally [26,27].

Conclusion

This study highlights that MRI-based measures of cartilage degeneration and meniscal pathology show similar associations with uni- and bicompartmental radiographic JSW measures, while bicompartmental JSW measures show stronger correlations with KL grades. These findings emphasize the importance of incorporating both compartments in KOA assessments, as reliance on

unicompartmental measures alone may not fully capture whole joint cartilage and meniscal morphology.

Ethical approval

All procedures performed in the IMI-Approach study were conducted in compliance with the protocol, Good Clinical Practice (GCP), the Declaration of Helsinki, and the applicable ethical and legal regulatory requirements (for all countries involved), and is registered under clinicaltrials.gov identifier: NCT03883568. Informed consent was obtained from all individual participants included in the study.

Contributions

Study conception and design: EB, HW, SM, MJ. Acquisition of data: MK, HR, FJB, IH, FB, FR. Analysis & interpretation of data: EB, RC, NvE, MK, HW, SM, MP. Writing of first manuscript draft: EB. Critical manuscript revision and approval of final manuscript: All authors. EB had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Declaration of Competing Interest

- Eva Bax: None
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- Nienke van Egmond: None
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- Hassan Rayegan: None
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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.joca.2025.11.011.

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