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Clinical Value of Weight-Bearing CT and Radiographs for Detecting Patellofemoral Cartilage Visualized by MRI in the MOST Study

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Abstract

Objective: The patellofemoral joint is frequently affected by osteoarthritis (PFOA) and is incompletely imaged on radiographs (XR). Weight-Bearing CT (WBCT) could offer advantages

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NAS and JAL contributed to the study conception and design. NAS, BME, KDB, JAL, MCN completed data collection. NAS and JH contributed to data analysis and interpretation. NAS and MTM drafted the manuscript. All authors provided comments and revised the manuscript. All authors provided final approval of the manuscript. NAS supervised all aspects of this study.

Competing Interests:
The authors declare no competing interests.

for visualization. This study determined the sensitivity, specificity, and accuracy of axial WBCT and lateral XR for detection of PFOA features in comparison with cartilage damage on MRI.

Design: A convenience sample of 60 right knees from the MOST cohort were analyzed. WBCT and XR were read for OARSI JSN score and MRI for MOAKS cartilage score by two experienced musculoskeletal radiologists blinded to participant. Using MOAKS scoring on MRI (referent standard), the sensitivity, specificity and accuracy of patellofemoral OARSI JSN scores based on WBCT and XR were compared. Results: The mean±SD age and BMI for the participants included (66.7% women) were 67.6±9.8 years and 30.0±5.3 kg/m^2 respectively. WBCT demonstrated significantly greater sensitivity (0.85–0.97 on WBCT vs. 0.47–0.57 on XR) and accuracy (0.85–0.92 on WBCT vs. 0.48–0.57 on XR) for all parameters except lateral full-thickness cartilage loss (McNemar's test p-values all <0.001). There was moderate-to-strong and low-to-moderate agreement between PFOA findings on WBCT and XR, respectively, and semi-quantitative scores of PF cartilage on MRI. Inter-rater reliability for XR JSN [weighted kappa=0.83 (0.64, 1.0)], WBCT JSN [kappa=0.60 (0.48, 0.72)] and MRI MOAKS-CM [kappa=0.70 (0.61, 0.79)] readings were good.

Conclusion: WBCT demonstrates significantly greater sensitivity and accuracy than radiographs for identification of PFOA. Given the same Relative Radiation Level as XR and improved visualization, WBCT holds promise to improve understanding of the weight-bearing patellofemoral joint.

Keywords

patellofemoral osteoarthritis; weight-bearing CT; radiographs; sensitivity; accuracy

INTRODUCTION:

Osteoarthritis (OA) is prevalent and the knee is the most commonly affected weight-bearing joint[1]. There are significant societal and personal costs associated with knee OA[2], yet little progress has been made in developing candidate therapeutics. The slow progress in developing therapeutics for OA may be explained partially by limitations of radiography (XR), the most common imaging modality in clinical trials[3]. Radiography is insensitive, fails to detect knee joint changes for years after damage begins and requires years to detect signs of worsening[4, 5]. Introduction of imaging biomarkers that are responsive to structural changes in the joint, as well as patient-reported outcomes, would hasten therapeutic progress.

While there are different phenotypes of osteoarthritis of the knee that may have unique etiopathologies, evidence suggests that isolated patellofemoral osteoarthritis (PFOA) may precede development of tibiofemoral osteoarthritis (TFOA) in many cases[6]. Stefanik *et al.* reported that OA is more likely to start in the patellofemoral joint and then progress to the tibiofemoral compartments in individuals with symptoms of early knee OA[7]. Similarly, Duncan *et al.* also found that tibiofemoral OA was often preceded by isolated PFOA and thus PFOA may serve as a marker of risk for whole knee OA[8].

In addition to risk for knee OA progression, those with PFOA report greater disability than those with medial TFOA[9]. Evidence from cross-sectional radiographic and magnetic resonance imaging (MRI) studies demonstrates that patellofemoral involvement contributes to symptoms and may be more important than the tibiofemoral compartment in explaining knee OA symptoms[10]. For example, patellofemoral osteophytes were associated with knee pain, while tibiofemoral osteophytes were not[11]. The degree of patellar cartilage volume loss on MRI has also been reported to be associated with worse Western Ontario and McMaster Universities Arthritis Index (WOMAC) pain and function scores[10]. In contrast, neither femoral nor tibial cartilage volume was strongly associated with WOMAC scores[10]. Malalignment of the patella in the trochlea also has been found to correlate with pain, OA development and OA progression[12–14]. However, while in some studies, grading of the lateral patellar facet on skyline view has been reported to moderately correlate with intraoperative Outerbridge grading[15], the validity and reliability of radiographic scoring of PFOA has been found to be low[16–18].

While there is evidence of association between symptoms and structural findings of PFOA, these findings have been more prominent on MRI than on radiographs. Furthermore, for patellofemoral radiography, there is no consensus on imaging methods, knee joint positioning, grading scale, weight bearing status, flexion angle or beam direction[19]. Due to the differences in radiographic imaging protocols, data could not be pooled in a recent meta-analysis of patellofemoral imaging and symptoms[20]. The lack of consensus not only indicates that the patellofemoral joint remains understudied, but also may relate to sub-optimal visualization of PFOA with radiographic imaging.

Given that PFOA is an important source of knee symptoms and may presage involvement of the tibiofemoral compartment[21], imaging that correlates with both structural disease and patient symptoms is necessary. Weight-bearing computed tomography (WBCT) imaging of the patellofemoral joint, using a low dose scanner may more accurately reflect cartilage morphology, enabling improved grading of disease status. Prior studies have found that WBCT is more sensitive and accurate than radiographs for detecting tibiofemoral osteophytes and subchondral cysts[22], more sensitive than MRI for detecting meniscal extrusion[23], and tibiofemoral measurements on WBCT correlate significantly better with Whole-Organ Magnetic Resonance Imaging Score (WORMS) cartilage morphology than measurements on radiographs[24]. The fact that WBCT imaging has the same Relative Radiation Level[25], is comparable in cost, requires less time to perform, and provides a great deal more imaging information in comparison to biplanar radiographs are advantages.

Imaging with WBCT holds potential to improve understanding of the weight-bearing patellofemoral joints beyond what is possible with radiographs, given the thinner slices, the ability to view the joint more completely on multiplanar 3D reconstructions and the greater sensitivity to visualizing soft-tissues in and around the joint. Therefore, this study aimed to determine the sensitivity, specificity, and accuracy of axial WBCT and lateral radiographs as surrogate measures for cartilage damage visualized on MRI.

METHODS:

Participants and Design

This cross-sectional study was conducted ancillary to the NIH-funded Multicenter Osteoarthritis Study (MOST), which investigated people with or at elevated risk for knee OA in order to identify opportunities for prevention and treatment. The current study was approved by the MOST Executive Committee to be conducted at the University of Iowa (UI) clinic site. Although participants at this site were drawn from the surrounding communities, with age and sex distributions similar to those for the US population with knee OA (60% women) and racial and ethnic distributions representative of Iowa City and the surrounding areas, our convenience sample may not be representative of the U.S. population as a whole. This study recruited participants at the 144 month visit for the parent MOST study. The local Investigational Review Board approved the study (IRB #201602741) and the observational study was registered as NCT03446404.

The original cohort of UI-MOST is comprised of participants with higher likelihood of disease progression. Participants were over age 64 at this visit and, at the MOST baseline visit, had at least one of the following three characteristics: overweight or obese, knee pain or stiffness on most of the prior 30 days, or a history of knee injury or surgery. The new cohort of participants recruited at this UI-MOST visit was comprised of participants with milder or no knee symptoms, and either no or minimal radiographic OA to enable study of early OA: age 45–69, had mild-to-moderate knee pain in one/both knees, with neither knee having constant pain that was of severe or greater intensity and both knees KL grade <2 based on the combined TF and PF compartments. A small subgroup with no knee pain was also recruited. The primary recruitment methods for the MOST study were mass mailings of letters, study brochures, and media and community outreach campaigns. Eligible participants were identified through health maintenance organization membership databases, voter registration tapes, commercial list brokers, and other sources.

Participants from the original and new cohort were eligible for this cross-sectional study if they underwent lateral radiographs, axial WBCT and 1.5T MRI imaging at the 144-month UI MOST clinic visit. For selection of existing participants, 84-month radiographs were screened and for new participants, recruited at the 144-month visit, screening radiographs were used. After excluding knees with known severe PFOA, a random number generator was used to select a sample containing approximately 30 with and 30 without radiographic evidence of PFOA. This sample was comprised of participants in the original (N=43) and new (N=17) cohorts. Since WBCT was acquired only at the UI-MOST site, only MOST participants from this site were eligible. Knees were not eligible if they had tibiofemoral KL 3–4 at the 84-month visit, since lateral radiographs and MRI were not acquired at the 144-month MOST visit for those knees. Eligibility for the present study began December 19th 2016, when 1.5T MRI acquisition was initiated. Exclusion criteria for the parent MOST Study included: inflammatory arthritis, inability to walk independently, serious health conditions (e.g., end-stage renal disease, cancer except non-melanoma skin cancer, severe heart failure), or reported inability to attend the 168-month follow-up visit (24 months following the visit for the current study).

Radiographic, WBCT, and MRI Acquisition Protocols

All participants underwent fixed-flexion weight-bearing lateral knee radiographs, fixed-flexion, non-contrast WBCT, and non-weight-bearing, slightly-flexed MRI with standardized technique and positioning per MOST protocol[26]. The weight-bearing lateral radiograph acquisition protocol positioned the standing participant perpendicular to the bucky device with the leg closest to the bucky in front and bent[27]. The Synaflexor frame was positioned with the plexiglass plate perpendicular to the bucky and just in front of the participant. The participant pressed the lateral aspect of his/her front knee against the bucky forcing the patella to contact the plexiglass plate of the Synaflexor frame. The participant was then asked to place the toes of the back foot against the heel of the front foot so as to provide consistency in the flexion angle. The central x-ray was then aimed at the tibiofemoral joint line with the femoral condyles positioned perpendicular to the bucky.

Similar to fixed-flexion radiography, the WBCT acquisition protocol placed participants' toes and the medial surfaces of their feet against vertical portions of a custom footplate to allow for fixed external rotation of 10° as previously depicted and described[28, 29]. The great toes, patellae, and anterior superior iliac spines were positioned coplanar to each other using a positioning frame with an anterior pelvic coronal bar and parasagittal greater trochanteric bar. This allowed for a knee flexion angle of approximately 20°. Participants were able to rest their hands on handrails to minimize motion. WBCT images (CurveBeam, Warrington, PA) were acquired utilizing cone-beam reconstruction, with a scan spanning 20cm height × 35cm width × 35cm depth (533 slices over 360° projection angle) using standard patient settings (120 kVp, 5 mA). The effective radiation dose for this scan was approximately 20 μSv, equivalent to the average environmental background radiation that is experienced when living 2–3 days at sea level.

MRI was used as the reference standard. Unlike lateral XR and axial WBCT, participants were imaged in a non-weight-bearing, slightly-flexed position. The MRI acquisition protocol[15] utilized a 1.5 T extremity scanner (model GE Optima MR430s, GE Healthcare, Waukesha, WI) with a dedicated knee coil to assess morphology of the medial and lateral patellofemoral cartilage on axial proton-density weighted fat-suppressed (PDFS) fast spin echo sequences. The repetition time (TR) was 4000–5000 ms, echo time (TE) 11ms, field of view 14cm (axial) to 160mm (sagittal), matrix 256×192, and slice thickness 3mm with no gap.

Radiographic, WBCT, and MRI Assessment

Imaging interpretation was performed by two musculoskeletal radiologists with greater than 10 years of experience reading radiographs, CT and MRI (BE, KB). To calibrate their ratings prior to beginning reading, investigators were provided with examples of Osteoarthritis Research Society International (OARSI) joint space narrowing (JSN) radiographic grades (0=none, 1=minimal, 2=moderate, 3=total joint-space loss) and MRI Osteoarthritis Knee Score (MOAKS)[30]. Given that no atlas for patellofemoral JSN existed, a modified scoring system of OARSI JSN was developed to include medial and lateral patellofemoral compartments using the protocol described by Jones *et al.*[31]. This modified scoring system

for joint space narrowing was used when scoring the most narrowed area within the patellofemoral joints on both lateral radiographs and axial non-contrast WBCT.

For WBCT, the medial and lateral patellofemoral joint spaces were graded separately with the patellar ridge included in the medial joint assessment. Joint space narrowing was graded on a 0–3 scale as follows: 0 = Normal, 1= Mild (<25% narrowing), 2 = Moderate (25–75%), 3 = Severe (>75%). Secondary factors such as accompanying osteophyte formation, subchondral sclerosis and subchondral cysts were considered for joints that were borderline between two categories and could be used to upgrade the categorization. Classification was performed independently by the two radiologists, blinded to the results of the plain film and MRI results for each participant.

Readers were blinded to participant identifiers and disease status through use of coded files. Different participant codes for each imaging modality were used and images for each modality were presented separately at the time of reading. Semi-quantitative scoring using MOAKS cartilage score for medial and lateral PF cartilage on MRI for 1) extent (area) of cartilage loss and 2) depth (% full thickness) of cartilage loss were defined as follows: 0=None, 1=<10% of region of cartilage surface area, 2=10–75% of region of cartilage surface area, 3=>75% of region of cartilage surface area. The radiologists provided composite scores combining the patellar and femoral cartilage in each compartment (e.g., a medial PF area of cartilage loss score and a medial PF depth of cartilage loss score). Of note, the lateral XR necessitated a single score for medial and lateral patellofemoral compartments. Both musculoskeletal radiologists scored all 60 right knees independently for assessment of inter-reader agreement and, 6 months later, generated consensus readings that were used for calculation of diagnostic value.

Statistical Analyses:

To calculate sensitivity, specificity, and accuracy of identification of joint space pathology in comparison with a) any cartilage loss and b) full-thickness cartilage loss visualized on MRI (reference standard), OARSI JSN scores on lateral radiographs and axial WBCT and MOAKS scores on MRI were dichotomized into zero vs. all other grades. McNemar's test was used to assess for statistically significant differences in sensitivity, specificity and accuracy, comparing lateral XR and axial WBCT to axial MRI, where accuracy was expressed as a proportion of correctly classified participants (true positives + true negatives) among all participants (true positives + true negatives + false positives + false negatives). Given the possibility that XR may be more effective in discriminating at more severe levels of OA, sensitivity analyses were performed in which OARSI JSN scores on lateral radiographs and axial WBCT and MOAKS scores on MRI were dichotomized into <2 vs. ≥2. Since XR had a single score for OARSI JSN based on a single superimposed lateral view, the single score on XR was paired with each of the medial and lateral MRI scores. Axial WBCT had independent medial and lateral scores and those scores were paired with the respective compartmental MRI scores. To control for the presence of medial and lateral compartment assessments on WBCT and MRI but not on XR, an additional sensitivity analysis was performed in which The medial and lateral WBCT and MRI grades were combined into a single score for each parameter.

Weighted kappa coefficients were calculated to assess inter-reader agreement. Inter-reader reliability was calculated using the independent readings and diagnostic performance (sensitivity, specificity, accuracy, etc.) was calculated using consensus readings. Kappa <0.20 indicated no agreement, 0.21 – 0.39 minimal, 0.40 – 0.59 weak, 0.60 – 0.79 moderate, 0.80 – 0.90 strong, and >0.90 almost perfect agreement[32]. Correlation between percent cartilage loss (any and full thickness) on MRI and severity of modified OARSI JSN readings on each modality (XR and WBCT) was described by calculating Spearman's rho and associated 95% confidence intervals for each comparison.

For this comparative diagnostic test study to detect a difference in sensitivity of 0.5 by lateral radiographs vs. 0.9 on axial WBCT, with a prevalence of patellofemoral cartilage lesions of 70% at a statistical power of 0.89 and alpha level of 0.039 would require sample sizes of 12 and 17 respectively and at a prevalence of 60% would require sample sizes of 18 and 30 respectively[33, 34]. Due to the availability of participants, a sample size of 60 was selected to assure adequate sample size to detect differences in sensitivity even if the prevalence were slightly lower or the differences in sensitivities between the modalities were slightly smaller than those proposed above, while avoiding problems of oversampling.

Results:

Participants (N=60; 66.7% women) had a mean±SD age and body mass index (BMI) of 67.6±9.8 years and 30.0±5.3 kg/m^2 respectively. Additional participant characteristics are presented in Table 1.

Axial WBCT was found to be more sensitive and accurate than lateral radiographs for identifying medial and lateral patellofemoral cartilage loss ($p<0.001$), medial patellofemoral full thickness cartilage loss ($p<0.001$), and lateral patellofemoral full thickness cartilage loss ($p<0.001$ for sensitivity, $p=0.1306$ for accuracy) (Table 2). Specificity could not be calculated for identification of any cartilage lesion due to zero false potitive and only one negative case precluding reliable estimates of specificity. Lateral radiographs demonstrated higher specificity than axial WBCT for lateral patellofemoral full thickness cartilage loss ($p=.0039$) (Diagnostic Value in Table 2 and Raw Data in Table 3).

Sensitivity analyses in which cases were defined by JSN score ≥2 support these findings (Table 4). Additional sensitivity analyses in which medial and lateral scores were combined for WBCT and MRI also supported the overall results with WBCT sensitivities of .90 (.82, .98) and .96 (.87, 1) for any cartilage damage and full-thickness cartilage damage respectively, in comparison with .47 (.34, .59) and .53 (.39, .66) on radiographs and similar results for specificity and accuracy to those for the primary analyses (Supplementary Table). The prevalence of XR, WBCT, and MRI features are presented in Table 5. Examples of scores that diverged between 3D and 2D assessments are presented in Figures 1–2.

Inter-rater reliability was strong for lateral XR JSN [weighted kappa = 0.83 (0.64, 1.0)], and moderate for axial WBCT JSN [kappa = 0.60 (0.48, 0.72)] and MRI MOAKS-CM [kappa = 0.70 (0.61, 0.79)]. When comparing between modalities, Spearman correlation coefficients were somewhat greater between PFOA JSN on axial WBCT and semi-quantitative scores

of PF cartilage on MRI (0.62–0.73). There was low-to-moderate agreement between PFOA JSN on lateral XR and semi-quantitative scores of PF cartilage on MRI (0.45–0.58) (Table 6).

Discussion:

This study assessed the diagnostic value of using measures of JSN on lateral XR and axial WBCT as surrogate markers for cartilage damage on MRI. Surrogate markers can have advantages when they provide an acceptable level of diagnostic value in concert with time or fiscal efficiency. Axial WBCT was significantly more sensitive and accurate than lateral radiographs for detection of any cartilage loss ($p<0.0001$) and full-thickness cartilage loss ($p<0.0001$ for all except lateral patellofemoral accuracy ($p=0.1306$)). Axial WBCT better correlated with semi-quantitative scores of patellofemoral cartilage on MRI than did lateral radiographs. Inter-rater reliability was excellent for lateral XR (weighted kappa = 0.83) and moderate for axial WBCT JSN (kappa = 0.60) and MRI (kappa=0.70). This may reflect possible shortcomings with the modified OARSI grading system developed for WBCT or perhaps investigator inexperience with using these grading systems for the patellofemoral joint.

Despite being the mainstay of diagnosis and monitoring knee OA, radiography can be insufficiently sensitive and may fail to detect knee joint damage for years after disease onset. The current study supports prior findings, which demonstrated WBCT to be more sensitive and accurate for detecting osteophytes and subchondral cysts in addition to correlating significantly better with WORMS cartilage morphology than PA and lateral radiographs[24]. Factors known to contribute to sensitivity include the type of views obtained, weight bearing status, and flexion angle[35].

There is lack of agreement with regard to optimal radiographic views for the patellofemoral joint. Use of either a skyline or lateral view has been shown to increase detection of PFOA with similar magnitudes of effect[36]. While skyline views are generally considered to be superior, they are more difficult to obtain[37, 38]. The present study found lateral radiographic sensitivity of 0.47–0.57. However, sensitivity of XR has been variable in prior studies. McDonnell *et al.*, using intraoperative assessment as a referent standard, reported that lateral views had poor sensitivity at 0.05–0.23 for all grades of disease. Skyline views had good sensitivity for grade 4 (large full thickness) damage at 0.90 but less so for grades 1–3 at 0.19–0.46[16–18]. Bhattacharya *et al.*, also using intraoperative assessment as referent standard, reported sensitivities of 0.82 and 0.79 for lateral and skyline views, respectively[37]. It appears that the sensitivity of radiographs may be variable with differences in imaging acquisition protocols and definitions of OA as previously described[19, 20].

Obtaining fixed-flexion views for lateral XR and axial WBCT (approximately 20° flexion), we were able to visualize the functional position of the patella when in apposition to the femur under functional muscle forces at the angle most common during the loading response phase of gait. Standing weight-bearing views with the knee flexed have consistently demonstrated reduced lateral tilt and medial translation of the patella relative to the trochlear groove in comparison to supine non-weight-bearing positions[39–42]. The result is enhanced

visualization of medial PFOA in weight-bearing radiographs in comparison to non-weight-bearing images[43]. Thus, lack of weight bearing is a principal reason that medial PFOA is frequently missed on radiographs. Although the standardized standing, fixed-flexed imaging acquisition protocol for both lateral XR and axial WBCT resulted in higher sensitivity for patellofemoral features than in prior studies[16–18], the sensitivity of lateral XR in this study remained lower than that for axial WBCT. Conversely, the specificity of lateral XR (0.68–1.00) was higher than that for axial WBCT (0.32–1.00) with MRI dichotomization into zero vs all other grades. However, this difference was attenuated in the sensitivity analysis based on defining cases by MRI dichotomization into <2 vs. ≥2 with specificities of 0.90–0.95 and 0.78–0.87 for lateral XR and axial WBCT, respectively. Lateral XR had a false positive rate of zero for most parameters (Table 3), indicating that if XR shows JSN, it is truly present. This is supported by previous studies[16–18] and the present study, whereby specificity approached 1.0 for most measures.

The utilization of knee flexion and weight-bearing positions during image acquisition for WBCT positioned the usual places of patellar cartilage loss next to the usual places of trochlear groove cartilage loss[39–42]. This is in contrast to non-weight bearing MRI and conventional computed tomography (CT) which typically do not have these areas adjacent to each other due to differences in knee flexion angle, lack of muscle forces and lack of weight bearing[44–46] Thus, non-weight-bearing MRI and CT may require additional axial slices through the patella to visualize patellar cartilage loss and more distal axial or sagittal slices to visualize trochlear groove cartilage loss. In addition to utilizing standing, fixed-flexed positions during image acquisition, axial WBCT confers additional advantages over lateral XR. Specifically, CT enhances joint visualization by avoiding bony overlap, utilizing thinner slices, and having capacity for multiplanar reconstruction. These advantages resulted in improved sensitivity and accuracy over lateral XR in the present study using the methods described.

While differences in imaging acquisition protocols may play a role in the sensitivity of radiographs[19, 20], it seems unlikely that standardization of protocols would significantly improve sensitivity in comparison to WBCT. The image acquisition protocol and reading completed as part of the MOST study is likely more meticulous than that used in clinical practice. Furthermore, a survey of Orthopedic Surgeons in the United Kingdom reported that more than 70% do not use the skyline view in routine practice for knee OA[47]. Nevertheless, the sensitivity of lateral XR remained lower than that of axial WBCT in the present study.

Study Limitations:

There were several limitations in this study. First, radiologists were provided with written instructions for modified OARSI JSN scores and MOAKS cartilage score, but no in-person training in the scoring systems was provided, which potentially attenuated inter-rater agreement. However, consensus readings were completed for the primary study objectives—sensitivity, specificity and accuracy. Second, radiographic skyline view, which has been shown to outperform lateral view[38], was not obtained in MOST and thus not available for analysis in this study. Consequently, a single lateral view was compared to both medial and lateral patellofemoral joint MRI measures, although results of sensitivity analyses enhanced

confidence in the overal results (Supplementary Table). Lastly, other measurements, such as those reported to correlate with patellofemoral pain[20] were not included in the current study, which focused on comparing WBCT and lateral XR with cartilage damage visualized on MRI.

Study Implications:

The patellofemoral joint is the most commonly affected compartment in knee OA[19], often precedes the development of TFOA, and has an isolated prevalence of up to 40%[7, 19]. Radiographs have historically been the imaging modality approved by the U.S. Food and Drug Administration for detecting and monitoring structural progression of knee OA in Phase 3 clinical trials. However, the insensitivity of radiographs coupled with incomplete visualization of the patellofemoral joint on lateral XR has heightened the need for novel imaging biomarkers to optimize clinical care. For assessing presence of PFOA using the methods described, axial WBCT offers superiority over lateral XR in sensitivity and accuracy and more strongly agrees with MRI, while maintaining the same relative radiation level and cost of radiographs. This coupled with thinner slices and more complete joint visualization on multiplanar reconstructions may allow WBCT to advance understanding of the weight-bearing patellofemoral joints beyond what is possible with conventional radiographic views.

Conclusion:

This study demonstrated significantly greater sensitivity and accuracy of axial WBCT over lateral radiographs as a surrogate measure of patellofemoral cartilage damage. Thus, WBCT holds potential to hasten therapeutic progress and reduce clinical trial cost and duration. Future studies should compare WBCT to skyline radiographs, include patient-reported outcomes, and image at a variety of standing knee flexion angles to further advance understanding of the structure of the weight-bearing patellofemoral joint.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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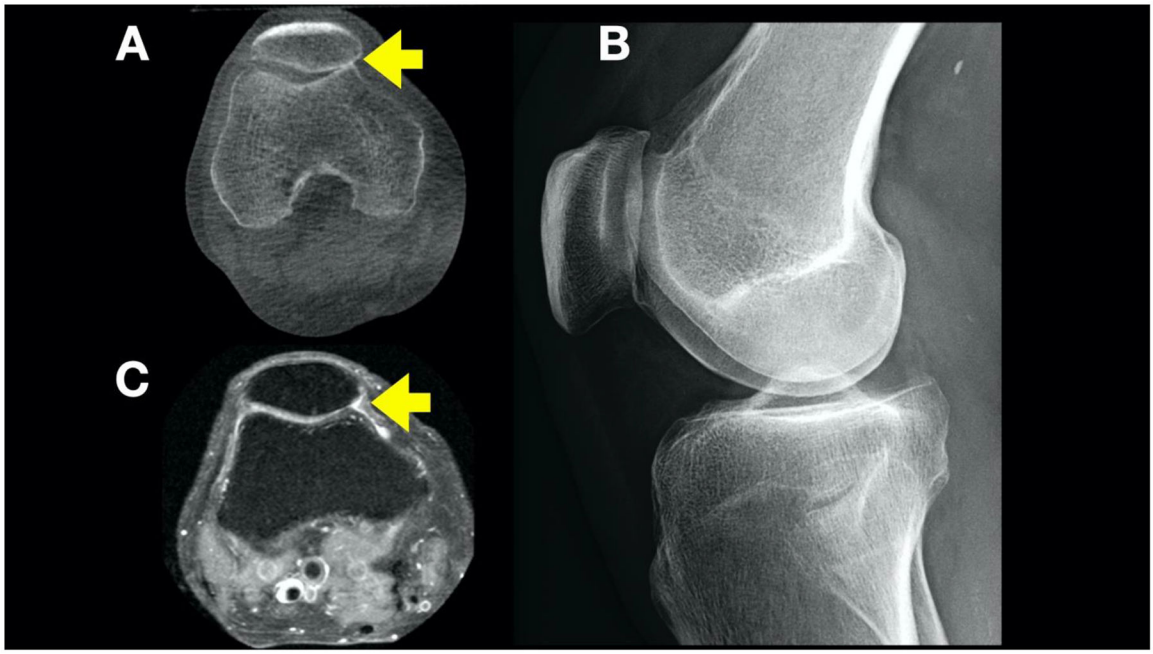

Figure 1.

(A) Superimposition of bones avoided on WBCT, allowing visualization of bone-on-bone contact with JSN scores of 3 medially (arrow) and 1 laterally. (B) The severity of OA in the medial patellofemoral joint is difficult to appreciate on lateral XR, which demonstrates JSN score of 0. (C) MRI demonstrates medial extent of cartilage loss score of 3, medial extent of full-thickness cartilage loss score of 3 (arrow), lateral extent of cartilage loss score of 3, and lateral extent of full-thickness cartilage loss score of 1.

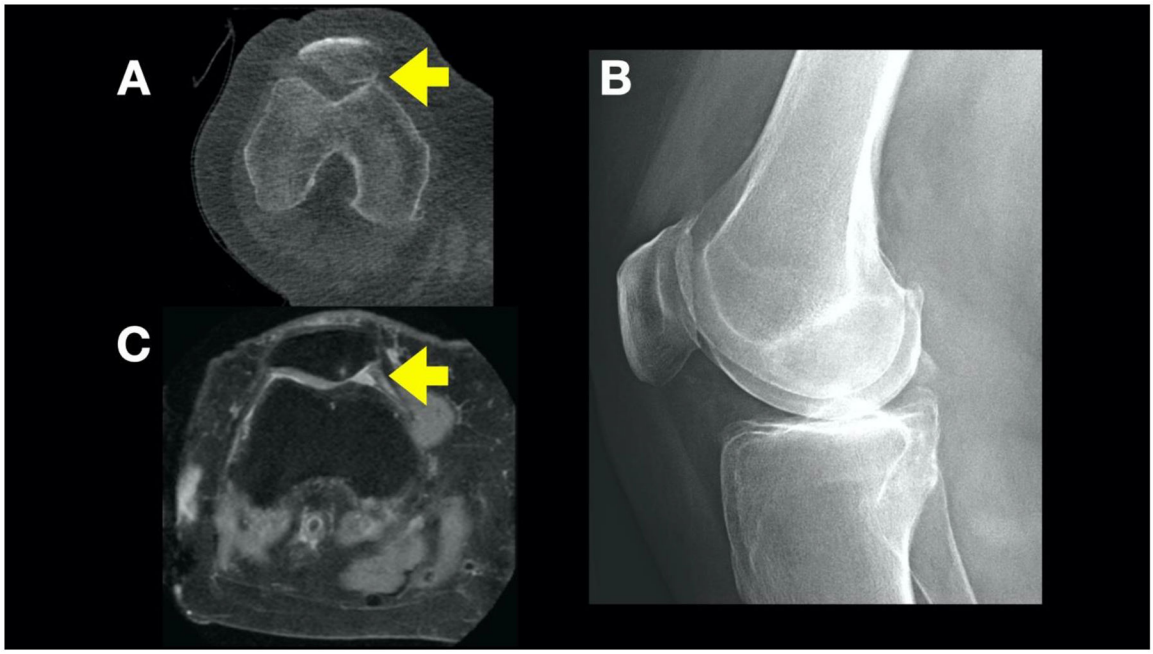

Figure 2.

(A) Functional tilt of the patella evident with weight-bearing muscle forces on WBCT, demonstrating medial patellofemoral bone-on-bone contact and JSN scores of 3 medially (arrow) and 1 laterally. (B) The severity of patellofemoral OA is difficult to appreciate on lateral XR, which demonstrates JSN score of 0. (C) MRI demonstrates medial extent of cartilage loss score of 3, medial extent of full-thickness loss score of 3 (arrow), lateral extent of cartilage loss score of 2, and lateral extent of full-thickness loss score of 1.

Table 1:

Participant Characteristics

Characteristic	Value
Male/Female (N=60)	20/40
Age, years	67.6±9.8
BMI, kg/m ^{2}	30.0±5.3
WOMAC Pain Sub-Score (Median, IQR)	0 (0, 2)
KL grade, %	
0	36%
1	14%
2	34%
3	16%
4	0%

Table 2:

Sensitivity, Specificity and Accuracy of XR and WBCT vs. MRI (dichotomized into JSN score 0 vs. all other grades)

		Sensitivity	p	Specificity	p	Accuracy	p
MRI Med. % Size vs. Med. JSN	XR	.47 (.35, .60)	<.0001	NC	NC	.48 (.36, .61)	<.0001
	WBCT	.85 (.76, .94)		NC		.85 (.76, .94)	
MRI Lat. % Size vs. Lat. JSN	XR	.52 (.39, .65)	<.0001	1 (.54, 1)	NC	.57 (.44, .69)	<.0001
	WBCT	.91 (.80, .97)		.67 (.22, .96)		.88 (.77, .95)	
MRI Med. % FT vs. Med. JSN	XR	.53 (.39, .66)	<.0001	1 (.59, 1)	NC	.48 (.36, .61)	<.0001
	WBCT	.92 (.82, .98)		.86 (.82, 1)		.92 (.82, .97)	
MRI Lat. % FT vs. Lat. JSN	XR	.57 (.41, .74)	<.0001	.68 (.50, .86)	.0039	.62 (.49, .74)	.1306
	WBCT	.97 (.92, 1)		.32 (.14, .50)		.70 (.58, .82)	

Med=medial patellofemoral compartment; Lat=lateral patellofemoral compartment; %Size=% of compartmental surface area with any cartilage loss; %FT=% of compartmental surface area with full thickness cartilage loss; JSN=OARSI JSN score for patellofemoral compartment (modified for WBCT); p=p-value comparing XR with WBCT; NC=non-calculable when parameter estimate is 1.

Table 3:

Frequencies of True and False Positive and Negative Results for XR and WBCT vs. MRI (dichotomized into JSN score 0 vs. all other grades)

		True Positive	False Positive	True Negative	False Negative
MRI Med. % Size vs. Med. JSN	XR	28	0	1	31
	WBCT	50	0	1	9
MRI Lat. % Size vs. Lat. JSN	XR	28	0	6	26
	WBCT	49	2	4	5
MRI Med. % FT vs. Med. JSN	XR	28	0	7	25
	WBCT	49	1	6	4
MRI Lat. % FT vs. Lat. JSN	XR	20	8	17	15
	WBCT	34	17	8	1

True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN); Med=medial patellofemoral compartment; Lat=lateral patellofemoral compartment; %Size=% of compartmental surface area with any cartilage loss; %FT=% of compartmental surface area with full thickness cartilage loss; JSN=OARSI JSN score for patellofemoral compartment (modified for WBCT).

Table 4:

Sensitivity, Specificity, and Accuracy of XR and WBCT vs. MRI (dichotomized into JSN score <2 vs ≥2)

		Sensitivity	Specificity	Accuracy
MRI Med. % Size vs. Med. JSN	XR	.27 (.14, .40)	.93 (.81, 1)	.43 (.31, .56)
	WBCT	.64 (.50, .78)	.87 (.69, 1)	.70 (.58, .82)
MRI Lat. % Size vs. Lat. JSN	XR	.28 (.14, .42)	.90 (.78, 1)	.50 (.37, .63)
	WBCT	.59 (.44, .74)	.86 (.71, 1)	.68 (.57, .80)
MRI Med. % FT vs. Med. JSN	XR	.30 (.16, .44)	.95 (.85, 1)	.51 (.39, .64)
	WBCT	.68 (.53, .82)	.80 (.62, .98)	.72 (.60, .83)
MRI Lat. % FT vs. Lat. JSN	XR	.47 (.25, .70)	.90 (.81, .99)	.77 (.66, .87)
	WBCT	.89 (.76, 1)	.78 (.65, .91)	.82 (.72, .91)

Med=medial patellofemoral compartment; Lat=lateral patellofemoral compartment; %Size=% of compartmental surface area with any cartilage loss; %FT=% of compartmental surface area with full thickness cartilage loss; JSN=OARSI JSN score for patellofemoral compartment (modified for WBCT)

Table 5:

Prevalence of XR, WBCT, and MRI Features

Features	Frequency of Grade				
	0	**1**	**2**	**3**	**Total**
MRI Med. % Size	1	14	19	26	60
MRI Med. % FT	7	13	21	19	60
MRI Lat. % Size	6	15	21	18	60
MRI Lat. % FT	25	16	9	10	60
WBCT Med. JSN	10	19	22	9	60
WBCT Lat. JSN	9	25	14	12	60
XR JSN	32	15	9	4	60

Med=medial patellofemoral compartment; Lat=lateral patellofemoral compartment; %Size=% of compartmental surface area with any cartilage loss; %FT=% of compartmental surface area with full thickness cartilage loss; JSN=OARSI JSN score for patellofemoral compartment (modified for WBCT)

Table 6:

Correlation of PFOA JSN on Axial WBCT and Lateral XR with Cartilage Lesions by MRI

Comparison	Modality	Spearman Correlation	95% CI
MRI Med. % Size vs. Med. JSN	XR	.52	(.30, .68)
	WBCT	.62	(.43, .75)
MRI Lat. % Size vs. Lat. JSN	XR	.45	(.22, .63)
	WBCT	.62	(.43, .76)
MRI Med. % FT vs. Med. JSN	XR	.58	(.38, .73)
	WBCT	.66	(.48, .78)
MRI Lat. % FT vs. Lat. JSN	XR	.47	(.24, .64)
	WBCT	.73	(.58, .83)

Med=medial patellofemoral compartment; Lat=lateral patellofemoral compartment; %Size=% of compartmental surface area with any cartilage loss; %FT=% of compartmental surface area with full thickness cartilage loss; JSN=OARSI JSN score for patellofemoral compartment (modified for WBCT)