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Validation of joint space narrowing on plain radiographs and its relevance to partial knee arthroplasty

RADIOLOGICAL AND MRI DATA FROM THE OSTEOARTHRITIS INITIATIVE

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Aims

To explore the clinical relevance of joint space width (JSW) narrowing on standardized-flexion (SF) radiographs in the assessment of cartilage degeneration in specific subregions seen on MRI sequences in knee osteoarthritis (OA) with neutral, valgus, and varus alignments, and potential planning of partial knee arthroplasty.

Methods

We retrospectively reviewed 639 subjects, aged 45 to 79 years, in the Osteoarthritis Initiative (OAI) study, who had symptomatic knees with Kellgren and Lawrence grade 2 to 4. Knees were categorized as neutral, valgus, and varus knees by measuring hip-knee-angles on hip-knee-ankle radiographs. Femorotibial JSW was measured on posteroanterior SF radiographs using a special software. The femorotibial compartment was divided into 16 subregions, and MR-tomographic measurements of cartilage volume, thickness, and subchondral bone area were documented. Linear regression with adjustment for age, sex, body mass index, and Kellgren and Lawrence grade was used.

Results

We studied 345 neutral, 87 valgus, and 207 varus knees. Radiological JSW narrowing was significantly ($p < 0.01$) associated with cartilage volume and thickness in medial femorotibial compartment in neutral ($r = 0.78$, odds ratio (OR) 2.33) and varus knees ($r = 0.86$, OR 1.92), and in lateral tibial subregions in valgus knees ($r = 0.87$, OR 3.71). A significant negative correlation was found between JSW narrowing and area of subchondral bone in external lateral tibial subregion in valgus knees ($r = –0.65$, $p < 0.01$) and in external medial tibial subregion in varus knees ($r = –0.77$, $p < 0.01$). No statistically significant correlation was found in anterior and posterior subregions.

Conclusion

SF radiographs can be potentially used for initial detection of cartilage degeneration as assessed by MRI in medial and lateral but not in anterior or posterior subregions.

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Keywords: Osteoarthritis cartilage, Joint space narrowing, Partial knee arthroplasty, Osteoarthritis radiography, Cartilage radiography

Article focus

- If, and to what extent, joint space narrowing width (JSW) of the femorotibial compartment predicts loss of cartilage volume and thickness and percentage of full-thickness cartilage defects.
- Does mechanical alignment of the lower limb affect cartilage degeneration in the different subregions of the knee, and if so, to what extent?
- Can radiological JSW assess cartilage degeneration in the anterior and posterior regions of the femorotibial joint?

Key messages

- JSW narrowing on plain radiographs indirectly but reliably measures central

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mediolateral cartilage degeneration in knee osteoarthritis (OA) with Kellgren and Lawrence grade of 2 to 4.
- Anterior and posterior cartilage damage such as in isolated anterior OA or purely posterior OA in the valgus knee cannot be sufficiently detected in the radiograph image.
- Limb malalignment is mostly associated with compartment-specific cartilage degeneration. Nonetheless, valgus knees demonstrated uncharacteristic high correlations in the medial compartment.

Strengths and limitations

- To our knowledge, the role of plain radiography has yet to be studied in assessing cartilage loss and degeneration in the various subregions of the femorotibial compartment of neutral, valgus, and varus knees.
- This study is limited by its retrospective nature. Although the Osteoarthritis Initiative (OAI) provided data for longitudinal studies, this study investigated data at a single point in time. Therefore statements regarding OA progression could not be made.
- Although their role might be indispensable, the contribution of intra-articular structures, such as meniscus, to JSW narrowing, was not investigated.

Introduction

Progressive degeneration of cartilage in the knee joint leads to joint pain and dysfunction that is clinically identified as knee osteoarthritis (OA). Despite being subjected to error secondary to reproducibility of joint position, beam alignment, and distance between the joint and film,[1] plain radiography remains a mainstay in the primary evaluation of OA and its progression by measuring joint space width (JSW) as an indirect assessment of cartilage degeneration, due to its accessibility and relatively low cost.[2] Along with clinical examination, radiological classification systems such as Kellgren and Lawrence (K&L) grading scheme[3] and Osteoarthritis Research Society International (OARSI) classification score[4] have been established to better guide evaluation of OA progression and clinical decision-making.[2,5]

Due to its excellent soft tissue imaging, ability to acquire morphological intra-articular data, and accuracy in measuring cartilage volume, thickness, and surface area, MRI is the current gold standard for primary assessment of knee OA and detection of its progression.[6-11]

The Osteoarthritis Initiative (OAI) is a public domain research database used to conduct longitudinal observational studies of prospective plain radiography and MRI data to analyze cartilage changes in knee OA.[12] Cartilage volume and thickness changes in the femorotibial compartment have been reported by several studies.[6,13,14] Maschek et al[13] reported that the presence of radiological JSW narrowing in knees with K&L grade 2 is associated with greater rates of cartilage thickness loss in comparison to K&L grade 1 knees. Among others (body mass index (BMI), physical activity, sex, meniscal pathologies, cartilage, or bone marrow lesions),[15,16] mechanical factors such as limb malalignment play an important role in progression of knee OA.[17-21]

Since first-line treatment of OA is highly dependent on clinical symptoms and their correspondent radiological morphologies, an accurate evaluation of cartilage status is required. For example, the typical OA to be treated with a unicompartimental knee arthroplasty (UKA) is an anteromedial OA that occurs in full extension. On the contrary, lateral OA, due to hypoplasia of the lateral femoral condyle among other aetiologies, is typically located posteriorly at the tibia and occurs in flexion. Although numerous studies have investigated loss of cartilage volume and thickness as well as degeneration of subchondral area seen in MRI sequences, nobody has studied yet, to our knowledge, the role of plain radiography in predicting cartilage loss and degeneration in subregions of neutral, valgus, and varus knee. Therefore, the correlation of degenerative changes seen on plain radiography in knee OA with quantitative cartilage loss seen on MRI sequences was investigated to specifically address the following questions: 1) does joint space narrowing of the femorotibial compartment predict loss of cartilage volume and thickness and percentage of full-thickness cartilage defects, and if so, to what extent?; 2) does mechanical alignment of the lower limb affect cartilage degeneration in the different subregions of the knee, and if so, to what extent?; and 3) can radiological joint space narrowing assess cartilage degeneration in the anterior and posterior regions of the femorotibial joint?

Methods

Cohort. This study uses the publicly available data from the OAI, a multicentre, longitudinal, prospective observational study of OA of the knee.[12] The overall purpose of the OAI is to develop a public domain research resource to facilitate the scientific evaluation of factors that influence the onset and progression of OA.

A total of 3,106 patients aged 45 to 79 years who were at risk of developing OA of the knee[12] were enrolled in the study. Clinical assessment of the knee and disease activity, radiographs, and MRIs were carried out once at baseline visit. Details of the cohort have been published on the OA website.[12]

Proper candidate selection was by focusing on ‘OA knees’ with complete MR images and a subsequent posteroanterior (PA) radiograph at baseline visit. A complete set of MRIs included the following sequences: coronal intermediate-weighted 2D turbo spin-echo, sagittal intermediate-weighted 2D turbo spin-echo fat suppression, sagittal 3D dual-echo in steady state water excitation, axial multiplanar reformation, and coronal multiplanar reformation.

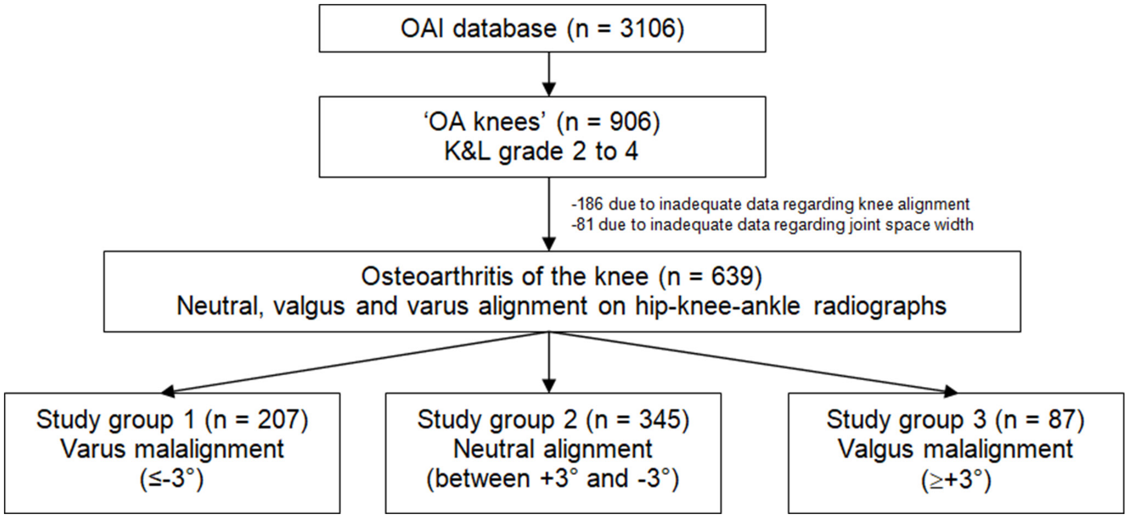

Fig. 1

Flow diagram presenting the subjects investigated from the entire Osteoarthritis Initiative Cohort. OAI, Osteoarthritis Initiative.

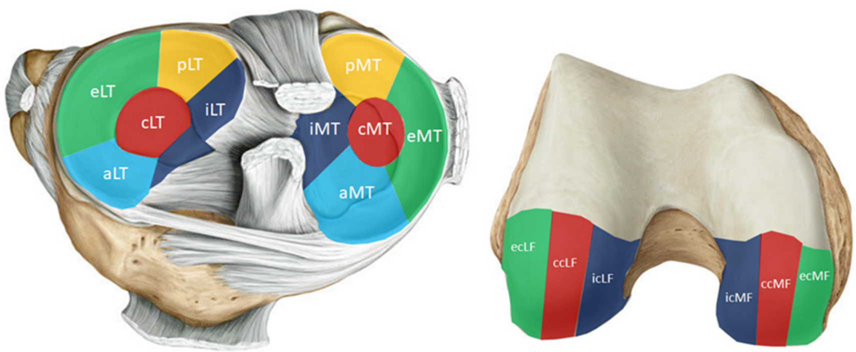

Fig. 2

The analyzed subregions at the tibia (left) and the femur (right). aLT, anterior lateral tibia; aMT, anterior medial tibia; ccLF, central lateral femur; ccMF, central medial femur; cLT, central lateral tibia; cMT, central medial tibia; ecLF, external central lateral femur; ecMF, external central medial femur; eLT, external lateral tibia; eMT, external medial tibia; icLF, internal central lateral femur; icMF, internal central medial femur; iLT, internal lateral tibia; iMT, internal medial tibia; pLT, posterior lateral tibia; pMT, posterior medial tibia.

'OA knees' were defined as symptomatic knees with K&L grade 2 to 4,[3] of which there were 906 available. The quantitative measurements of normalized cartilage volume, percentage of area of subchondral bone denuded of cartilage, and mean cartilage thickness on MRI were recorded by the OAI as 'Eckstein measurements'.[14] The study included all knees with neutral, valgus, and varus alignments.

Of the 906 subjects, 186 were excluded due to inadequate data regarding knee alignment and 81 were excluded due to inadequate data regarding joint space width. By assessing hip-knee-ankle standing radiographs (measurements available at baseline visit, intraclass correlation coefficient (ICC) 0.98), limb alignment was determined, dividing the remaining 639 knees in 345, 87, and 207 knees in neutral (hip-knee-ankle angle between -3° and +3°), valgus (hip-knee-ankle angle ≥ +3°), and varus (hip-knee-ankle angle ≤ -3°) subgroups, respectively (Figure 1). In the neutral subgroup, 52 and 42 knees had hip-knee-ankle angles between -3° and -2°, and between +2° and +3°, respectively.

Image analyses: MRI. The volume and thickness of the cartilage and the area of articular cartilage defects were analyzed using sagittal double-echo steady-state (DESS) sequences. Reporting details and nomenclature for the evaluation of the MRIs are reported on the OAI website.[12] The method of making these measurements was described by Eckstein et al[14] and Wirth et al.[10]

The following measurements were recorded: normalized cartilage volume (cartilage volume divided by total area of subchondral bone in cm^2), mean cartilage thickness (mm), and percentage of area of subchondral bone denuded of cartilage.[10,14] Separate measurements were made for femoral and tibial sub-/regions.

The 16 subregions were defined as the internal, central, external, anterior, and posterior portions of the medial and lateral tibial plateau as well as internal,

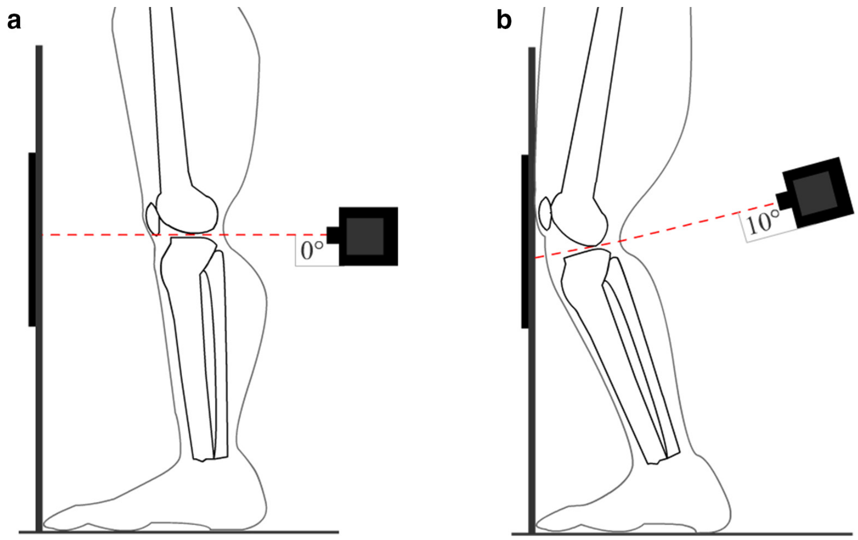

Fig. 3

Posteroanterior radiography with a) upright standing position with the great toes touching the anterior wall of the frame and both feet in 10° external rotation, and b) both knees and thighs pressed against the anterior wall of the frame in order to fix flexion of the knees, resulting in vertical alignment of the patella, toes, and chest. The x-ray beam is angled 10° caudal and centred at the level of the joint line until the anterior and posterior margins of the tibial plateau superimposed.

central, and external portions of the medial and lateral femoral compartment (Figure 2).[14]

Radiographs. Knee alignment was identified by hip-knee-angles (HKAs) on standing radiographs of the lower limbs ('full-limb') radiographs.[12] Coronal alignment was defined as the angle between the mechanical axes of the femur and tibia.[22-24] Neutral, valgus, and varus knee alignments were defined as having a HKA between +3° and -3°, ≥ +3°, and ≤ -3°, respectively.

The joint space width (JSW) was determined from an OAI dataset which contains central longitudinal readings for the entire OAI cohort of serial knee radiographs.[12] These were carried out at the Brigham and Women's Hospital in Boston under the direction of Dr Jeffrey Duryea, PhD. The quantitative measurements of femorotibial JSW such as minimum JSW (mJSW) in the medial femorotibial compartment, as well as JSW at fixed locations in the femorotibial joint (medial to lateral), were determined from posteroanterior (PA) standardized-flexion (SF) knee radiographs (Figure 3). Further position details are as follows: upright standing position with equal distribution of body weight between the two legs, with the great toes touching the anterior wall of the frame, both feet are fixed in 10° external rotation by pressing them against the V-shaped support on the base of the frame. Both knees and thighs are pressed against the anterior wall of the frame in order to fix flexion of the knees, resulting in vertical alignment of the patella, toes, and chest. The radiograph beam is angled 10° caudal and centred at the level of the joint line. Final image acquisition was made when the tibial plateau of the medial compartment was horizontal. This occurred when the anterior and posterior margins of the tibial plateau were superimposed on the image as judged by the radiologist.[25] In contrast to Rosenberg and Lyon schuss views, which are PA weight-bearing knee radiographs taken in 45° and 30° of flexion, respectively, the PA standardized-flexion imaging technique investigated in this study uses 20° to 25° of knee flexion achieved by aligning the film with the tips of the toes, resulting in easier reproducibility.[26-28]

A customized software tool developed by Duryea et al[25] is used to provide measurements of the medial compartment mJSW, which is the smallest distance between the femoral and tibial joint margins, and fixed locations (x) of JSW along the joint on serial standardized-flexion knee radiographs from the OAI.[12] An anatomical coordinate system is defined, which permits an objective determination of the (x)-location. The software placed the x-axis automatically and the y-axis and a line defined as $x = 1$ were placed manually by Dr Jeffrey Duryea (Figure 4). Measurements of JSW at increments of 0.025 taken at $x < 0.5$ are for the medial, and at $x > 0.5$ for the lateral femorotibial compartment.[25] Measurements of alignment of anterior and posterior rims of the tibial plateau were not provided.

Statistical analysis. Linear regression with adjustment for age, sex, BMI, and K&L grade,[3] as well as Pearson's chi-squared test, was used. We calculated Pearson's *r* (r), odds ratios (ORs), and 95% confidence intervals (95% CIs) to assess the relationship between JSW narrowing and cartilage degeneration. A p-value of < 0.05 was considered to be statistically significant. All statistical analyses were performed using IBM SPSS software version 23 (IBM Corporation, Armonk, New York).

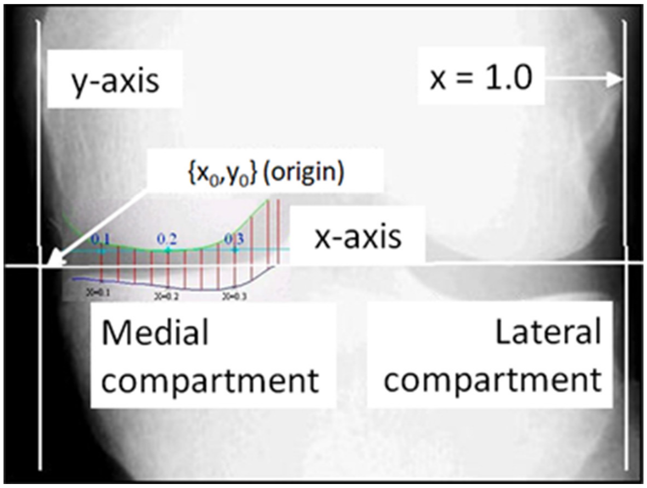

Fig. 4

Measurements of femorotibial joint space width at increments of 0.025 using Duryea et al's[25] customized software tool.

Results

Radiological JSW narrowing was significantly associated with loss of cartilage volume (Table I), mainly in medial femorotibial compartment in neutral and varus knees (r = 0.78, OR 2.33 (95% CI 2.12 to 2.54) and r = 0.86, OR 1.92 (95% CI 1.77 to 2.08), respectively), and in lateral tibial subregions in valgus knees (r = 0.87, OR 3.71 (95% CI 3.26 to 4.17)).

A statistically significant correlation was found between loss of cartilage thickness and JSW narrowing (Table II) in central medial femoral subregion in neutral knees (r = 0.8, OR 1.85 (95% CI 1.7 to 1.99)), in central and external lateral tibial subregions in valgus knees (r = 0.86, OR 1.75 (95% CI 1.53 to 1.97) and r = 0.86, OR 3.22 (95% CI 2.82 to 3.63), respectively), and in external medial tibial subregion in varus knees (r = 0.87, OR 2.68 (95% CI 2.47 to 2.88)).

Although no significant association ($-0.54 < r < 0.18$) was found between area of subchondral bone denuded of cartilage and JSW narrowing (Table III) using Pearson's correlation coefficient in neutral knees, it was found that valgus and varus knees exhibited a negative correlation in external lateral tibial (r = –0.65, p = 0.002) and external medial tibial (r = –0.77, p = 0.003) subregions.

Analysis of the various parameters using Pearson's correlation coefficient did not show a strong correlation (r < 0.7) in anterior and posterior subregions despite statistical significance (p = 0.008).

Figures 5 to 7 demonstrate the varying low to high correlations of cartilage volume loss, cartilage thickness loss, and area of subchondral bone denuded of cartilage, respectively, of the various femorotibial subregions with respect to their (x)-position in the joint space.

Discussion

The main finding of this study is the confirmation of a highly significant correlation between radiological JSW narrowing and MRI-based femorotibial cartilage defects in osteoarthritic knees. With respect to the other structures in the knee joint, JSW narrowing on plain radiographs indirectly but reliably measures central mediolateral cartilage degeneration in knee OA with K&L grade of 2 to 4. Cartilage damage in the anterior and posterior subregions, such as in isolated anterior OA (possibly indication for medial UKA) or purely posterior OA in the valgus knee, cannot be sufficiently detected in standardized-flexion (SF) AP radiography. Cartilage degeneration is greatly influenced by limb alignment. Variations of cartilage defects in the different subregions of femorotibial joint contribute to a better understanding of OA development and progression.

JSW narrowing in knees with neutral alignment exhibited high predictability of loss of cartilage thickness and volume in the central medial femoral and tibial subregions, with consistent findings in location x = 0.225 (Tables I to III). No correlation whatsoever was found in the lateral compartment. This phenomenon might be explained by the stance phase knee adduction moment, which contributes to higher load exertion in the medial compartment.[29-31] Similar observations of a significant reduction in cartilage thickness in the weight-bearing medial femoral condyle were reported by Eckstein et al,[14] among others,[13,32] who also reported greater changes in cartilage thickness than in volume in the femorotibial compartment in a one-year follow-up study of 156 subjects with knee OA.

Consistent with previous radiological and biomechanical reports,[20,33,34] this study reveals and reinforces the fact that cartilage degeneration is greatly associated with limb malalignment. Valgus knees with radiological JSW narrowing exhibited mostly lateral cartilage loss of thickness and volume, and significant correlation to area of subchondral bone denuded of cartilage in MRI sequences, especially in internal, central, and external tibial subregions. Although similar associations have been observed in the femoral subregions, the correlation with tibial degeneration was significantly higher. Highest values of significant correlation in the lateral compartment were seen consistently in location x = 0.775 (Tables I to III). Interestingly enough, valgus knees were found to radiologically predict cartilage degeneration in the medial compartment as well. Significant correlations, with values similar to those in neutral knees, were found between radiological JSW narrowing and loss of cartilage volume and thickness in the medial femoral weight-bearing region and central femoral and tibial subregions, respectively. This finding contradicts the hypothesis that only lateral joint tissue alterations are seen with valgus malalignment and, furthermore, possibly indicates that an incipient valgus OA on SF radiographs could be somewhat obscured and only in the further course, when the medial compartment is involved, is actually detectable. This finding might be an interesting future research direction.

Table I. Pearson's correlation coefficient of cartilage volume loss and joint space narrowing at (x)-location in each of the femorotibial subregions in knees with neutral, valgus, and varus alignments.

Alignment	(x)-location	Femur (weight-bearing region)		Tibia		Femorotibial compartment	
		Medial	Lateral	Medial	Lateral	Medial	Lateral
Neutral							
Medial	mJSW	0.671*†	0.171*	0.526*	0.220*	0.666*†	0.229*
	0.150	0.668*†	0.165*	0.530*	0.216*	0.665*†	0.223*
	0.175	0.683*†	0.176*	0.569*	0.261*	0.692*†	0.257*
	0.200	0.742*‡	0.248*	0.621*†	0.316*	0.752*‡	0.330*
	0.225	0.758*§	0.259*	0.650*†	0.350*	0.775*‡	0.358*
	0.250	0.757*‡	0.282*	0.678*†	0.389*	0.786*§	0.394*
	0.275	0.744*‡	0.293*	0.686*†	0.401*	0.780*‡	0.407*
	0.300	0.723*‡	0.298*	0.677*†	0.394*	0.762*‡	0.406*
Lateral	0.700	0.304*	0.278*	0.240*	0.568*	0.302*	0.505*
	0.725	0.324*	0.325*	0.278*	0.597*	0.332*	0.548*
	0.750	0.354*	0.441*	0.395*	0.701*‡	0.400*	0.674*†
	0.775	0.309*	0.474*	0.405*	0.692*†	0.374*	0.686*†
	0.800	0.270*	0.468*	0.369*	0.654*†	0.333*	0.660*†
	0.825	0.220*	0.394*	0.298*	0.572*	0.270*	0.569*
	0.850	0.197*	0.367*	0.259*	0.542*	0.238*	0.536*
	0.875	0.158*	0.332*	0.217*	0.497*	0.195*	0.489*
	0.900	N	0.246*	0.124¶	0.399*	0.107¶	0.381*
Valgus							
Medial	mJSW	0.548*	N	0.594*	N	0.609*	N
	0.0150	0.452*	N	0.489*	N	0.502*	N
	0.175	0.564*	0.238¶	0.580*	N	0.614*	0.224¶
	0.200	0.707*‡	0.213¶	0.702*‡	N	0.759*‡	N
	0.225	0.725*‡	0.258¶	0.697*†	N	0.768*‡	0.241¶
	0.250	0.746*‡	0.322*	0.688*†	0.236¶	0.777*‡	0.299*
	0.275	0.749*‡	0.353*	0.668*†	0.262¶	0.770*‡	0.329*
	0.300	0.757*‡	0.389*	0.656*†	0.284*	0.770*‡	0.360*
Lateral	0.700	0.213¶	0.552*	N	0.802*‡	0.217¶	0.746*‡
	0.725	0.232¶	0.629*	N	0.844*‡	0.221¶	0.808*‡
	0.750	N	0.653*†	N	0.860*‡	N	0.830*‡
	0.775	N	0.693*†	N	0.871*§	N	0.856*‡
	0.800	N	0.666*†	N	0.826*‡	N	0.817*‡
	0.825	N	0.650*†	N	0.820*‡	N	0.805*‡
	0.850	N	0.632*	N	0.810*‡	N	0.790*‡
	0.875	N	0.481*	N	0.680*†	N	0.638*
	0.900	N	0.442*	N	0.645*	N	0.598*
Varus							
Medial	mJSW	0.813*‡	-0.140¶	0.703*†	N	0.817*‡	N
	0.150	0.785*‡	-0.014¶	0.683*†	0.171¶	0.790*‡	N
	0.175	0.806*‡	-0.131	0.709*†	0.187*	0.815*‡	N
	0.200	0.822*‡	-0.133	0.740*†	0.194*	0.837*‡	N
	0.225	0.822*‡	-0.118	0.746*†	0.193*	0.839*‡	N
	0.250	0.817*‡	-0.107	0.754*†	0.210*	0.839*‡	N
	0.275	0.837*§	-0.029	0.780*†	0.270*	0.863*§	N
	0.300	0.800*‡	0.002	0.760*†	0.286*	0.831*‡	0.158†
Lateral	0.700	0.369*	0.240*	0.430*	0.583*	0.414*	0.457*
	0.725	0.343*	0.303*	0.406*	0.591*	0.387*	0.497*
	0.750	0.304*	0.385*	0.367*	0.600*	0.346*	0.548*
	0.775	0.223*	0.404*	0.307*	0.560*	0.268*	0.537*
	0.800	0.189*	0.445*	0.283*	0.556*	0.236*	0.558*
	0.825	N	0.505*	0.139¶	0.532*	N	0.580*
	0.850	N	0.330*	N	0.344*	N	0.377*
	0.875	N	0.304*	0.152¶	0.313*	N	0.345*
	0.900	N	0.276*	0.151¶	0.282*	N	0.312*

*Significant at 0.01 level.
†Low statistical correlation (0.65 < r < 0.7).
‡High statistical correlation (r ≥ 0.7).
§Highest statistical correlation in its alignment group.
¶Significant at 0.05 level.
mJSW, minimum joint space width; N, values with no statistical significance.

Table II. Pearson's correlation coefficient of cartilage thickness loss and joint space narrowing at (x)-location in each of the femorotibial subregions in knees with neutral, valgus, and varus alignments.

Alignment	(x)-location, mJSW	Medial femur			Lateral femur			Medial tibia					Lateral tibia				
		Ext.	Cent.	Int.	Int.	Cent.	Ext.	Ext.	Ant.	Post.	Cent.	Int.	Int.	Ant.	Post.	Cent.	Ext.
Neutral																	
Medial	mJSW	0.636*	0.711*†	0.513*	0.195*	0.175*	N	0.722*†	0.421*	0.283*	0.565*	0.274*	0.302*	0.153*	0.161*	0.187*	N
	0.150	0.622*	0.710*†	0.505*	0.215*	0.180*	N	0.694*‡	0.429*	0.294*	0.547*	0.311*	0.302*	0.163*	0.127§	0.192*	N
	0.175	0.624*	0.725*†	0.532*	0.213*	0.194*	N	0.721*†	0.457*	0.330*	0.595*	0.338*	0.334*	0.212*	0.177*	0.228*	N
	0.200	0.662*‡	0.778*†	0.597*	0.266*	0.243*	0.155*	0.752*†	0.499*	0.348*	0.669*‡	0.389*	0.371*	0.277*	0.205*	0.279*	0.162*
	0.225	0.670*‡	0.800*¶	0.605*	0.269*	0.261*	0.165*	0.766*†	0.513*	0.370*	0.709*†	0.416*	0.408*	0.292*	0.230*	0.318*	0.179*
	0.250	0.656*‡	0.798*†	0.616*	0.281*	0.282*	0.198*	0.763*†	0.537*	0.388*	0.739*†	0.455*	0.433*	0.328*	0.249*	0.359*	0.226*
	0.275	0.628*	0.773*†	0.633*	0.277*	0.295*	0.221*	0.737*†	0.544*	0.395*	0.749*†	0.493*	0.433*	0.353*	0.256*	0.368*	0.252*
	0.300	0.597*	0.734*†	0.643*	0.272*	0.301*	0.238*	0.685*‡	0.550*	0.384*	0.731*†	0.535*	0.398*	0.372*	0.257*	0.356*	0.268*
Lateral	0.700	0.189*	0.327*	0.325*	0.254*	0.338*	0.199*	0.285*	0.176*	0.129§	0.266*	0.198*	0.601*	0.325*	0.465*	0.572*	0.369*
	0.725	0.205*	0.336*	0.349*	0.293*	0.369*	0.253*	0.297*	0.231*	0.143*	0.304*	0.231*	0.599*	0.377*	0.461*	0.607*	0.417*
	0.750	0.251*	0.345*	0.379*	0.376*	0.482*	0.363*	0.344*	0.334*	0.236*	0.409*	0.353*	0.655*‡	0.485*	0.522*	0.705*†	0.523*
	0.775	0.201*	0.292*	0.351*	0.377*	0.500*	0.429*	0.293*	0.350*	0.265*	0.408*	0.396*	0.594*	0.521*	0.470*	0.699*‡	0.580*
	0.800	0.172*	0.253*	0.310*	0.350*	0.489*	0.450*	0.255*	0.322*	0.250*	0.374*	0.369*	0.533*	0.505*	0.439*	0.662*‡	0.585*
	0.825	0.146*	0.206*	0.256*	0.280*	0.416*	0.394*	0.191*	0.285*	0.209*	0.303*	0.296*	0.448*	0.440*	0.395*	0.585*	0.534*
	0.850	0.118§	0.184*	0.236*	0.271*	0.374*	0.374*	0.164*	0.265*	0.192*	0.257*	0.252*	0.408*	0.428*	0.360*	0.554*	0.522*
	0.875	N	0.149*	0.201*	0.241*	0.335*	0.341*	0.124§	0.232*	0.154*	0.217*	0.222*	0.387*	0.376*	0.337*	0.510*	0.456*
	0.900	N	N	0.155*	0.174*	0.257*	0.257*	N	0.117§	0.109§	0.139*	0.136§	0.328*	0.276*	0.269*	0.413*	0.360*
Valgus																	
Medial	mJSW	0.421*	0.512*	0.446*	0.318*	N	N	0.590*	0.443*	0.465*	0.576*	0.507*	N	N	N	N	N
	0.150	0.425*	0.312*	0.453*	0.292*	N	N	0.528*	0.371*	0.478*	0.432*	0.369*	0.218§	N	N	N	N
	0.175	0.523*	0.455*	0.513*	0.466*	0.225§	N	0.607*	0.450*	0.521*	0.553*	0.475*	0.291*	N	N	N	N
	0.200	0.533*	0.686*‡	0.608*	0.438*	N	N	0.665*‡	0.565*	0.562*	0.707*†	0.620*	0.237§	N	N	N	N
	0.225	0.534*	0.714*†	0.630*	0.455*	0.251§	N	0.635*	0.561*	0.547*	0.723*†	0.630*	0.255§	N	N	N	N
	0.250	0.538*	0.739*‡	0.663*‡	0.488*	0.315*	N	0.608*	0.553*	0.530*	0.733*†	0.643*	0.283*	0.220§	N	N	N
	0.275	0.532*	0.741*‡	0.677*‡	0.495*	0.347*	N	0.564*	0.538*	0.511*	0.725*†	0.642*	0.296*	0.240§	0.220§	0.225§	N
	0.300	0.552*	0.733*‡	0.686*‡	0.497*	0.384*	N	0.518*	0.556*	0.486*	0.706*†	0.655*‡	0.286*	0.279*	0.214§	0.250§	0.215§
Lateral	0.700	N	0.219§	0.307*	0.333*	0.524*	0.563*	N	N	N	0.252§	0.266§	0.737*†	0.624*	0.599*	0.777*†	0.692*‡
	0.725	N	0.247§	0.313*	0.402*	0.611*	0.618*	N	N	N	0.259§	0.273§	0.727*†	0.645*	0.629*	0.824*†	0.797*†
	0.750	N	0.225§	0.273§	0.384*	0.636*	0.671*‡	N	N	N	0.234§	0.253§	0.718*†	0.672*‡	0.646*	0.845*†	0.820*†
	0.775	N	0.218§	0.268§	0.386*	0.673*‡	0.728*†	N	N	N	0.237§	0.273§	0.690*‡	0.685*‡	0.634*	0.864*¶	0.863*†
	0.800	N	0.215§	0.257§	0.369*	0.635*	0.722*†	N	N	N	0.255§	0.291*	0.644*	0.645*	0.607*	0.824*†	0.834*†
	0.825	N	N	0.252§	0.348*	0.615*	0.716*†	N	N	N	0.252§	0.284*	0.633*	0.623*	0.614*	0.817*†	0.835*†
	0.850	N	N	0.233§	0.330*	0.591*	0.707*†	N	N	N	0.235§	0.268§	0.617*	0.597*	0.620*	0.806*†	0.825*†
	0.875	N	N	N	N	0.465*	0.584*	N	N	N	N	N	0.502*	0.486*	0.545*	0.696*‡	0.710*
	0.900	N	N	N	N	0.419*	0.585*	N	N	N	N	N	0.484*	0.487*	0.493*	0.665*‡	‡0.652*
Varus																	

Continued

Table II. Continued

Alignment	(x)-location, mJSW	Medial femur			Lateral femur			Medial tibia					Lateral tibia				
		Ext.	Cent.	Int.	Int.	Cent.	Ext.	Ext.	Ant.	Post.	Cent.	Int.	Int.	Ant.	Post.	Cent.	Ext.
Medial	mJSW	0.841*†	0.825*†	0.603*	N	N	N	0.876*¶	0.405*	0.453*	0.695*‡	0.285*	0.395*	N	0.144§	0.108	N
	0.150	0.809*†	0.796*†	0.576*	N	N	N	0.853*†	0.420*	0.415*	0.663*‡	0.302*	0.421*	N	0.176§	0.162§	N
	0.175	0.824*†	0.820*†	0.602*	N	N	N	0.852*†	0.441*	0.454*	0.695*‡	0.316*	0.435*	N	0.186*	0.177§	N
	0.200	0.841*†	0.836*†	0.616*	N	N	N	0.868*†	0.452*	0.486*	0.737*†	0.331*	0.439*	N	0.202*	0.182*	N
	0.225	0.835*†	0.835*†	0.627*	N	N	N	0.859*†	0.442*	0.509*	0.749*†	0.345*	0.433*	N	0.201*	0.175§	N
	0.250	0.822*†	0.827*†	0.636*	N	N	N	0.844*†	0.460*	0.510*	0.760*†	0.371*	0.437*	N	0.207*	0.196*	N
	0.275	0.827*†	0.839*†	0.676*‡	0.142§	N	N	0.835*†	0.468*	0.532*	0.790*†	0.433*	0.483*	N	0.245*	0.255*	N
	0.300	0.781*†	0.794*†	0.664*‡	0.149§	N	N	0.776*†	0.457*	0.524*	0.768*†	0.469*	0.474*	0.140§	0.261*	0.271*	0.125
Lateral	0.700	0.302*	0.372*	0.360*	0.342*	0.267*	0.149§	0.380*	0.313*	0.265*	0.420*	0.330*	0.687*‡	0.315*	0.375*	0.595*	0.366*
	0.725	0.251*	0.342*	0.383*	0.371*	0.335*	0.223*	0.299*	0.318*	0.253*	0.400*	0.382*	0.642*	0.364*	0.376*	0.612*	0.412*
	0.750	0.181*	0.294*	0.391*	0.415*	0.413*	0.314*	0.200*	0.313*	0.226*	0.356*	0.417*	0.571*	0.401*	0.369*	0.626*	0.470*
	0.775	N	0.211*	0.331*	0.394*	0.424*	0.356*	N	0.276*	0.170§	0.305*	0.413*	0.485*	0.398*	0.321*	0.590*	0.480*
	0.800	N	0.170§	0.323*	0.414*	0.457*	0.409*	N	0.272*	0.152§	0.270*	0.427*	0.469*	0.409*	0.308*	0.572*	0.505*
	0.825	N	N	0.195*	0.428*	0.479*	0.501*	N	0.166§	0.070	0.143§	0.333*	0.386*	0.407*	0.352*	0.523*	0.509*
	0.850	N	N	0.165§	0.274*	0.282*	0.383*	N	N	0.137§	0.134	0.348*	0.229*	0.246*	0.255*	0.337*	0.353*
	0.875	N	N	0.192*	0.247*	0.254*	0.359*	N	N	0.186*	0.158§	0.342*	0.234*	0.216*	0.235*	0.302*	0.306*
	0.900	N	N	0.143§	0.226*	0.231*	0.322*	N	N	0.200*	0.153§	0.309*	0.220*	0.176§	0.231*	0.272*	0.253*

N = values with no statistical significance.
*Correlation is significant at the 0.01 level.
†High statistical correlation ($r \geq 0.7$)
‡Low statistical correlation ($0.65 < r < 0.7$)
§Correlation is significant at the 0.05 level.
¶Highest statistical correlation in its alignment group.
Ant. , anterior; Cent., central; Ext., external; Int., internal; mJSW, minimum joint space width; Post., posterior.

Table III Pearson's correlation coefficient of percentage of subchondral bone denuded of cartilage and joint space narrowing at (x)-location in each of the femorotibial subregions in knees with neutral, valgus, and varus alignments.

Alignment	(x)-location, mJSW	Medial femur			Lateral femur			Medial tibia					Lateral tibia				
		Ext.	Cent.	Int.	Int.	Cent.	Ext.	Ext.	Ant.	Post.	Cent.	Int.	Int.	Ant.	Post.	Cent.	Ext.
Neutral																	
Medial	mJSW	-0.478*	-0.488*	N	0.163*	0.107†	N	-0.532*	-0.302*	-0.341*	-0.410*	-0.127†	N	N	N	N	0.155*
	0.150	-0.446*	-0.442*	N	0.107‡	0.023	N	-0.482*	-0.291*	-0.342*	-0.381*	-0.137†	N	N	N	N	0.172*
	0.175	-0.449*	-0.451*	N	0.175*	0.077	N	-0.496*	-0.287*	-0.354*	-0.385*	-0.151*	N	N	N	N	0.161*
	0.200	-0.467*	-0.465*	N	0.183*	0.113†	N	-0.519*	-0.283*	-0.330*	-0.402*	-0.143*	N	N	N	N	0.154*
	0.225	-0.463*	-0.474*	N	0.177*	0.112†	N	-0.525*	-0.294*	-0.341*	-0.420*	-0.153*	N	N	N	N	0.138†
	0.250	-0.450*	-0.469*	N	0.172*	0.094	N	-0.521*	-0.286*	-0.338*	-0.419*	-0.136†	N	N	N	N	0.113†
	0.275	-0.428*	-0.446*	N	0.179*	0.084	N	-0.500*	-0.283*	-0.324*	-0.417*	-0.123†	N	N	N	N	N
	0.300	-0.385*	-0.405*	N	0.167*	0.071	N	-0.445*	-0.278*	-0.295*	-0.385*	-0.113†	N	N	N	N	N
Lateral	0.700	-0.129†	-0.196*	-0.198*	N	-0.209*	-0.236*	-0.196*	-0.112†	-0.220*	-0.160*	N	-0.296*	N	-0.201*	-0.315*	-0.206*
	0.725	-0.119†	-0.192*	-0.181*	N	-0.150*	-0.201*	-0.191*	-0.111†	-0.172*	-0.157*	N	-0.285*	N	-0.177*	-0.251*	-0.167*
	0.750	-0.122†	-0.198*	-0.166*	N	-0.150*	-0.181*	-0.197*	-0.114†	-0.187*	-0.163*	N	-0.308*	N	-0.194*	-0.236*	-0.218*
	0.775	N	-0.126†	-0.132†	N	-0.149*	-0.223*	-0.118†	N	-0.147*	-0.123†	N	-0.212*	N	-0.142*	-0.226*	-0.243*
	0.800	N	N	N	0.121†	-0.140*	-0.225*	N	N	-0.136†	N	N	-0.172*	N	-0.124†	-0.209*	-0.247*
	0.825	N	N	N	0.152*	-0.116†	-0.205*	N	N	N	N	N	-0.141*	N	N	-0.183*	-0.235*
	0.850	N	N	N	0.163*	-0.130†	-0.224*	N	N	N	N	N	-0.122†	N	N	-0.233*	-0.263*
	0.875	N	N	N	0.162*	-0.118†	-0.204*	N	N	N	N	N	-0.106†	N	N	-0.226*	-0.252*
	0.900	N	N	-0.108†	0.135†	-0.111†	-0.211*	N	N	N	N	N	N	N	N	-0.203*	-0.228*
Valgus																	
Medial	mJSW	N	N	N	N	N	0.294*	-0.300*	0.102	N	-0.293*	N	N	N	0.230†	N	0.227†
	0.150	N	0.081	-0.434*	N	N	N	N	0.056	N	N	N	N	N	0.273†	N	N
	0.175	N	0.038	-0.352*	N	N	N	-0.260†	0.080	N	-0.255†	N	N	N	N	N	N
	0.200	N	N	N	N	N	N	-0.347*	0.053	N	-0.337*	-0.232†	N	N	N	N	N
	0.225	N	N	N	N	N	N	-0.327*	0.042	N	-0.314*	-0.213†	N	N	N	N	N
	0.250	N	N	N	N	N	N	-0.296*	0.037	N	-0.283*	N	N	N	N	N	N
	0.275	N	N	N	N	N	N	-0.232†	0.055	N	-0.218†	N	N	N	N	N	N
	0.300	N	N	N	N	N	N	N	0.060	N	N	N	N	N	N	N	N
Lateral	0.700	-0.227†	N	N	N	-0.344*	-0.456*	N	-0.264†	N	N	-0.231†	-0.356*	-0.380*	-0.300*	-0.524*	-0.526*
	0.725	-0.245†	N	N	N	-0.380*	-0.513*	N	-0.223†	N	N	-0.244†	-0.366*	-0.390*	-0.324*	-0.577*	-0.617*‡
	0.750	-0.242†	N	N	N	-0.412*	-0.572*	N	-0.231†	N	N	-0.242†	-0.363*	-0.418*	-0.335*	-0.609*‡	-0.624*‡
	0.775	-0.249†	N	N	N	-0.412*	-0.607*	N	-0.250†	N	N	-0.225†	-0.331*	-0.417*	-0.340*	-0.616*‡	-0.657*§
	0.800	-0.224†	N	N	N	-0.379*	-0.580*	N	-0.249†	N	N	-0.214†	-0.295*	-0.380*	-0.296*	-0.582*	-0.635*‡
	0.825	N	N	N	N	-0.358*	-0.563*	N	-0.283*	N	N	-0.215†	-0.278*	-0.355*	-0.295*	-0.564*	-0.636*‡
	0.850	N	N	N	N	-0.331*	-0.548*	N	-0.318*	N	N	N	-0.248†	-0.321*	-0.303*	-0.543*	-0.627*‡
	0.875	N	N	N	N	-0.306*	-0.509*	N	-0.308*	N	N	N	-0.213†	-0.294*	-0.268†	-0.497*	-0.576*
	0.900	N	N	N	N	-0.312*	-0.529*	N	-0.336*	N	N	N	N	-0.325*	-0.232†	-0.488*	-0.553*
Varus																	
Medial	mJSW	-0.735*¶	-0.670*‡	-0.330*	N	N	N	-0.767*¶	-0.477*	-0.481*	-0.632*‡	-0.254*	-0.179*	-0.296*	-0.153†	N	N
	0.150	-0.693*‡	-0.633*‡	-0.298*	N	N	N	-0.746*¶	-0.455*	-0.449*	-0.592*	-0.251*	-0.191*	-0.307*	-0.194*	N	N

Continued

Table III Continued

Alignment	(x)-location, mJSW	Medial femur			Lateral femur			Medial tibia					Lateral tibia				
		Ext.	Cent.	Int.	Int.	Cent.	Ext.	Ext.	Ant.	Post.	Cent.	Int.	Int.	Ant.	Post.	Cent.	Ext.
	0.175	-0.719*¶	-0.666*‡	-0.327*	N	N	N	-0.752*¶	-0.476*	-0.470*	-0.624*‡	-0.258*	-0.182*	-0.316*	-0.163†	N	N
	0.200	-0.743*¶	-0.695*‡	-0.353*	N	N	N	-0.777*§	-0.491*	-0.495*	-0.657*‡	-0.271*	-0.187*	-0.333*	-0.176†	N	N
	0.225	-0.743*¶	-0.701*¶	-0.371*	N	N	N	-0.776*¶	-0.488*	-0.514*	-0.672*‡	-0.287*	-0.191*	-0.346*	-0.171†	N	N
	0.250	-0.723*¶	-0.684*‡	-0.372*	N	N	N	-0.757*¶	-0.490*	-0.502*	-0.663*‡	-0.298*	-0.187*	-0.353*	-0.173†	N	N
	0.275	-0.697*‡	-0.656*‡	-0.381*	N	N	N	-0.735*¶	-0.438*	-0.506*	-0.653*‡	-0.313*	-0.180*	-0.324*	-0.192*	N	N
	0.300	-0.641*‡	-0.600*	-0.370*	N	N	N	-0.679*‡	-0.382*	-0.486*	-0.608*‡	-0.323*	-0.171†	-0.310*	-0.203*	N	N
Lateral	0.700	-0.229*	-0.257*	-0.150†	-0.155†	-0.155†	N	-0.293*	-0.224*	N	-0.245*	N	-0.351*	N	N	-0.189*	-0.160†
	0.725	-0.144†	-0.188*	N	-0.147†	-0.172†	N	-0.207*	-0.161†	N	-0.183*	N	-0.342*	N	N	-0.204*	-0.148†
	0.750	N	N	N	-0.138†	-0.178†	N	N	N	N	N	N	-0.234*	N	N	-0.213*	-0.139†
	0.775	N	N	N	N	-0.154†	N	N	N	N	N	N	-0.168†	N	N	-0.194*	N
	0.800	N	N	N	N	-0.140†	N	N	N	N	N	N	-0.196*	N	N	-0.186*	N
	0.825	0.199*	0.147†	N	N	N	N	0.185*	0.173†	N	0.153†	0.153†	-0.164†	N	N	-0.168†	N
	0.850	0.147†	N	N	N	N	N	0.153†	0.213*	N	N	N	N	N	N	N	N
	0.875	N	N	N	N	N	N	N	0.207*	N	N	N	-0.137†	N	N	N	N
	0.900	N	N	N	N	N	N	N	0.197*	N	N	N	-0.146†	N	N	N	N

N = values with no statistical significance.
*Correlation is significant at the 0.01 level.
†Correlation is significant at the 0.05 level.
‡Low statistical correlation ($-0.7 < r < -0.6$).
§Highest statistical correlation in its alignment group.
¶High statistical correlation ($r \le -0.7$).
Ant., anterior; Cent., central; Ext., exterior; Int., interior; mJSW, minimum joint space width; Post., posterior.

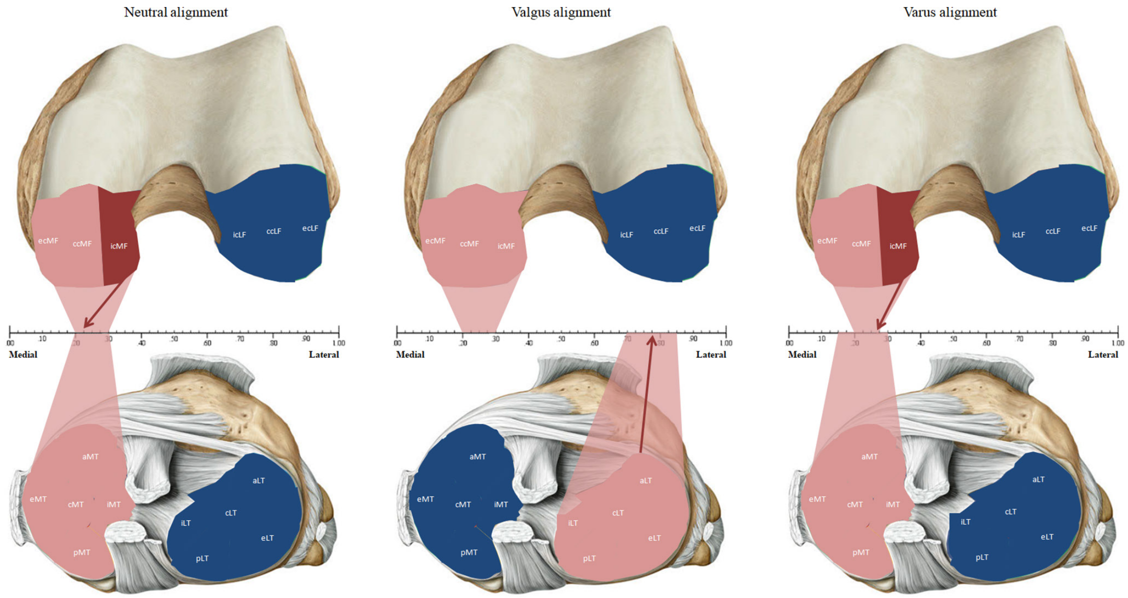

Fig. 5

Data derived from Table I show the analyzed subregions at the tibia (lower section) and the femur (upper section) with highlights of specific areas of high correlation between cartilage volume loss and its corresponding (x)-specific location. Colour-coded correlations: Blue area, subregion with low statistical correlation ($r < 0.7$); pink area, subregion with high statistical correlation ($r \geq 0.7$); red area, subregion with highest statistical correlation in its alignment group; arrow, (x)-location with highest statistical correlation in its alignment group. aLT, anterior lateral tibia; aMT, anterior medial tibia; ccLF, central lateral femur; ccMF, central medial femur; cLT, central lateral tibia; cMT, central medial tibia; ecLF, external central lateral femur; ecMF, external central medial femur; eLT, external lateral tibia; eMT, external medial tibia; icLF, internal central lateral femur; icMF, internal central medial femur; iLT, internal lateral tibia; iMT, internal medial tibia; pLT, posterior lateral tibia; pMT, posterior medial tibia.

In contrast to valgus knees, significant correlations in knees with varus malalignment were only seen in the medial compartment, with the highest values seen in the external, not central, femoral, and tibial subregions. Contrary to neutral and valgus knees, varus knees demonstrated an inhomogeneous distribution of correlation along the x-axis. While Duryea et al[35] suggested using $x = 0.275$ for neutral, $x = 0.725$ for valgus, and $x = 0.250$ for varus knees as optimal points for monitoring OA progression, better correlations in $x = 0.225$ in neutral, $x = 0.775$ in valgus, and $x = 0.275$ in varus knees were found in this baseline study. Neumann et al[36] reported that evaluation of medial OA progression for more diseased subjects (K&L grade 4) is best done in the more central portion of the knee ($x > 0.2$).

Although mJSW is often used as the standard metric to assess OA status and progression, JSW at fixed x-locations was found to better correlate to cartilage morphological alterations with the exception of cartilage thickness loss for all subjects (Table II). This finding is consistent with previous reports.[8,35] Nonetheless, results differ with various knee positioning protocols.[36-38] Le Graverand et al[38] compared the SF to a fluoroscopically guided protocol and found increased reproducibility and responsiveness of mJSW using the Lyon Schuss protocol.[39]

Cartilage degeneration in the anterior and posterior subregions of the femorotibial joint is not effectively assessed by radiological JSW on SF radiographs. This finding is consistent with a previous study.[40] Nonetheless, since the greatest femorotibial mechanical stress is achieved in 24° to 28° knee flexion[41] and the greatest cartilage wear of the weight-bearing region is located 30° to 60° posterior to the trochlear notch,[42,43] SF radiographs might be superior to conventional standing-view radiographs in full extension, which lack the biomechanical components to accurately estimate cartilage alterations.[40,42,44–46] This theorem is supported by the several discrepancies found between radiological and arthroscopic assessment of cartilage status.[40,45,47,48]

Precise radiological evaluation of compartmental cartilage status is essential in determination of both surgical and conservative treatment options available to the patient, especially when planning partial knee arthroplasty, particularly robotic-assisted and patient-specific, which due to its less invasive nature, shorter length of hospital stay, and faster recovery period has become an increasingly popular surgical alternative.[49–52] Among the various imaging techniques, standing AP, true lateral, skyline, and valgus and varus stress radiographs have been proposed as assessors of anteroposterior, isolated anteromedial, or posterolateral cartilage change.[53,54] Since this study analyzed radiographs acquired with a SF protocol and measurements of radiological JSW are highly dependent on knee positioning, we can make no assumptions regarding the application of our results to studies using different positioning techniques. This includes Rosenberg radiographs, which have been reported to demonstrate higher reliability than AP

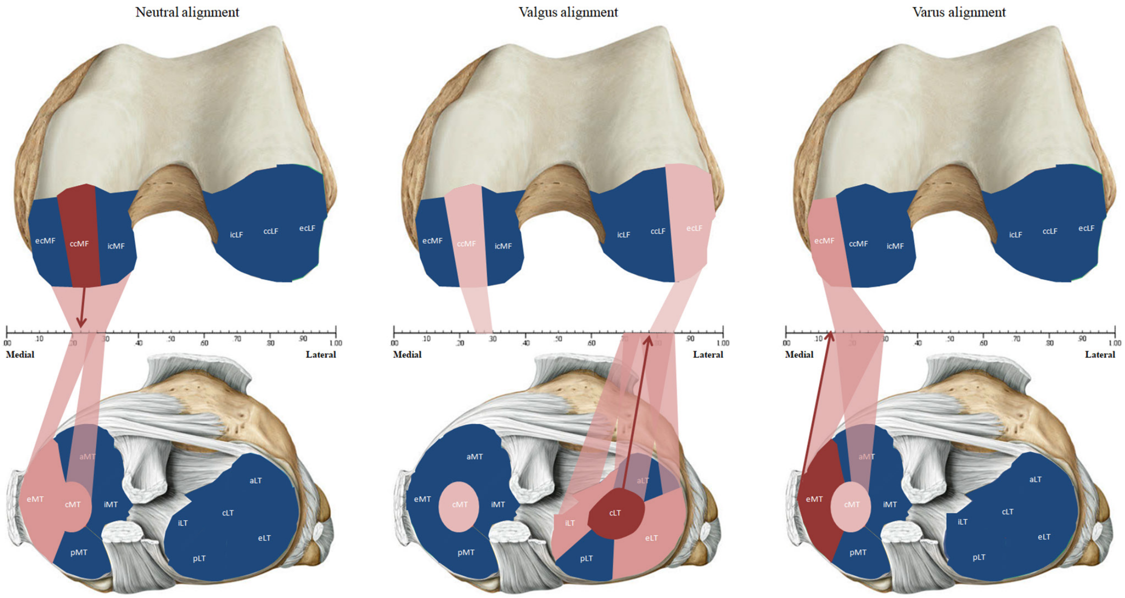

Fig. 6

Data derived from Table II show the analyzed subregions at the tibia (lower section) and the femur (upper section) with highlights of specific areas of high correlation between cartilage thickness loss and its corresponding (x)-specific location. Colour-coded correlations: Blue area, subregion with low statistical correlation ($r < 0.7$); pink area, subregion with high statistical correlation ($r \geq 0.7$); red area, subregion with highest statistical correlation in its alignment group; arrow, (x)-location with highest statistical correlation in its alignment group. aLT, anterior lateral tibia; aMT, anterior medial tibia; ccLF, central lateral femur; ccMF, central medial femur; cLT, central lateral tibia; cMT, central medial tibia; ecLF, external central lateral femur; ecMF, external central medial femur; eLT, external lateral tibia; eMT, external medial tibia; icLF, internal central lateral femur; icMF, internal central medial femur; iLT, internal lateral tibia; iMT, internal medial tibia; pLT, posterior lateral tibia; pMT, posterior medial tibia.

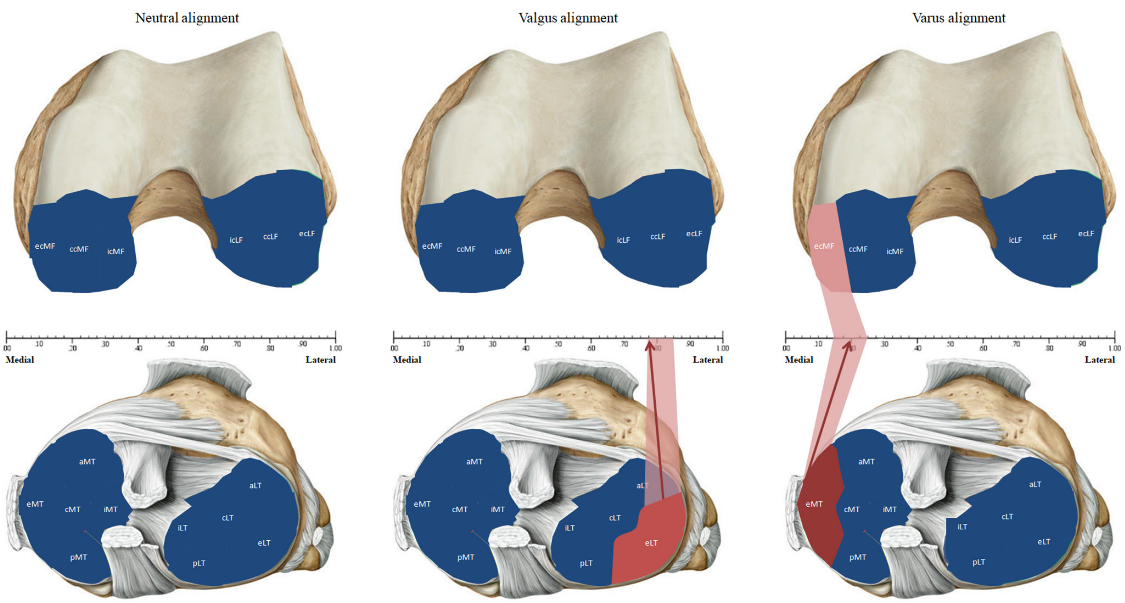

Fig. 7

Data derived from Table III show the analyzed subregions at the tibia (lower section) and the femur (upper section) with highlights of specific areas of high correlation between percentage of subchondral bone denuded of cartilage and its corresponding (x)-specific location. Colour-coded correlations: blue area, subregion with low statistical correlation ($r > -0.6$); pink area, subregion with high statistical correlation ($r \leq -0.7$); red area, subregion with highest statistical correlation in its alignment group; arrow, (x)-location with highest statistical correlation in its alignment group. aLT, anterior lateral tibia; aMT, anterior medial tibia; ccLF, central lateral femur; ccMF, central medial femur; cLT, central lateral tibia; cMT, central medial tibia; ecLF, external central lateral femur; ecMF, external central medial femur; eLT, external lateral tibia; eMT, external medial tibia; icLF, internal central lateral femur; icMF, internal central medial femur; iLT, internal lateral tibia; iMT, internal medial tibia; pLT, posterior lateral tibia; pMT, posterior medial tibia.

radiographs,[48] and fluoroscopically guided Lyon Schuss method, which, although reported as being more accurate for measurement of actual JSW, presumably due to its superiority in aligning the medial tibial plateau, is more complex, time-consuming, and increases the exposure dose.[38,42,46] The method of radiological image acquisition in this study has been reported to provide reproducible JSW measurements and a more feasible application in routine clinical use than methods that reply on fluoroscopic positioning.[28,55] Furthermore, the angulation of the tibial plateau in this position is determined primarily by the relative lengths of the tibia and foot, neither of which tend to change substantially over time in adults, resulting in great reproducibility of leg positioning.[28] Nonetheless, it would be of great clinical interest to compare further imaging protocols to the SF imaging technique investigated in this study.

Although 2D radiological measurements of JSW can indirectly evaluate cartilage status, they depend on the specific flexion angle of the knee and cannot reveal spatial patterns of cartilage loss, since the cartilage surfaces are not in direct contact in all parts of the joint. In contrast, MRI can be used to analyze articular cartilage morphology quantitatively, although its role in perioperative planning of potential UKA is still debated due to overestimation of the degree of joint pathology.[42,56] Direct visualization of soft tissue in the knee joint can also be done using weight-bearing MRI, which might provide a more functional dynamic assessment.[57] One study reported weight-bearing imaging as having more sensitivity to change in articular cartilage thickness than non-weight bearing MRI measurements in knees with K&L grade 3.[58] The effect of loading upon MRI-based femorotibial cartilage alterations in association with JSW narrowing on weight-bearing radiographs should be investigated.

This study is limited by its retrospective nature. Although OAI provided data for longitudinal studies, this study investigated data at a single point in time. Therefore, statements regarding OA progression could not be made. Although their role might be indispensable the contribution of intra-articular structures, such as meniscus, to JSW narrowing was not investigated. Previous studies reported that initial JSW narrowing, especially in the peripheral regions of the joint where hyaline cartilage is the thinnest and meniscus the thickest, is secondary to meniscal displacement beyond the outermost margin of the tibial plateau (extrusion oder subluxation) rather than thinning of joint cartilage.[59,60] However, only longitudinal studies can investigate the exact relationship between JSW narrowing and meniscal degeneration, which might be interdependent. Radiographs were limited to a single non-fluoroscopically guided protocol; therefore, propositions regarding similar results in other knee positioning techniques cannot be made. Although no continuous measures to assess progression of JSW narrowing were used, this study exhibited highly significant correlations at a single point in time.

Our data of a high number of subjects suggest that JSW on SF radiographs can reliably evaluate cartilage status primarily at central weight-bearing sites in neutral and valgus knee OA. Varus knees, however, exhibited better correlations in the external subregions. Limb malalignment is mostly associated with compartment-specific cartilage degeneration. Nonetheless, valgus knees demonstrated uncharacteristic high correlations in the medial compartment. The proportion of subjects in our study was comparable with findings in other large, community-based studies of subjects with knee OA, with some similar results. However, no study has investigated correlations in the various subregions in the three subgroups of subjects.

In conclusion, plain SF radiography can be potentially used for initial detection of femorotibial cartilage loss as assessed by MRI in medial femoral subregions in neutral knees, in lateral tibial subregions in valgus knees, and in medial tibial subregions in varus knees. Nevertheless, evaluation of cartilage status in the anterior and posterior subregions using SF radiography could not be made and might be done using further radiological protocols or MR-tomographical direct visualization of soft tissue, particularly when planning a potential UKA. Analysis suggests that JSW narrowing on SF radiographs often reflects cartilage degeneration in the central subregions of the weight-bearing surface in neutral and valgus knees. Exact assessment of cartilage status requires selective radiological imaging with weight-bearing protocol and correct alignment.

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