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Original article

Association between hip and knee cartilage measured using radiographs and magnetic resonance imaging: the Tasmanian Older Adult Cohort Study

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Abstract

Objective. Cartilage loss is a key pathological feature of OA and can be assessed indirectly using radiography or directly through MRI. A number of cross-sectional studies have suggested that primary generalized osteoarthritis (PGOA) may be a distinct disease, but despite the high frequency of involvement of the hip and the knee joints in OA, very few studies have looked at the radiographic association between these two joints, and none has done so using MRI. The aim of this study was to examine the association of hip and knee cartilage measured by both radiography and MRI.

Methods. We studied 151 participants from the Tasmanian Older Adult Cohort (TASOAC) study, who were selected randomly from the southern Tasmanian electoral rolls. MRI was used to assess hip and knee cartilage volume and radiography was used to assess joint space narrowing (JSN). Correlation analyses were used to compare cartilage volume measurements and JSN.

Results. In adjusted analysis, there was a consistent, positive association between knee and hip cartilage volume that was best for total knee cartilage volume ($r = 0.16$–0.40, all $P < 0.05$). In contrast, there was at best a weak correlation, depending on the site, between hip and knee JSN ($r = -0.01$ to 0.21).

Conclusion. Hip and knee cartilage volume are more strongly associated than hip and knee JSN, suggesting a commonality of cartilage volume at different anatomic sites. The weaker radiographic association may reflect less measurement error with MRI or the contribution of multiple structures to joint space in the knee.

Key words: osteoarthritis, knee, hip, cartilage volume, MRI, X-ray.

Introduction

OA commonly affects the hip and the knee joints [1–3] and a pathological signature is the loss of OA articular cartilage [4]. Cartilage loss can be detected indirectly by radiographic means, looking at joint space narrowing (JSN) or loss of joint space width (JSW), but such structural changes can only be detected at an advanced stage of the disease [5]. However, cartilage can also be directly evaluated by MRI, in which the volume can be quantitatively assessed [6, 7].

A number of cross-sectional studies have examined the association of hand OA with hip or knee OA [8–13], suggesting that primary generalized OA (PGOA) may be a

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distinct disease in which systemic predisposition is more important than local (mechanical) factors [14–17]. In a recently published study, Haugen *et al.* [18], found a positive association between radiographic hand JSN and knee cartilage volume determined by MRI, further suggesting that systemic predisposition plays an important role in the progression of this disease. However, despite the high frequency of involvement of the hip and knee joints in OA [1, 2], few studies have looked at the radiographic association of JSN/JSW in these two joints. Sayre *et al.* [19] found a weak but statistically significant association between hip and knee JSN using plain radiography in an elderly population. In another similar study, Kinds *et al.* [20] found a significant correlation between the hip and knee using a semi-quantitative measure of JSW assessed by digital radiography. These modest correlations may be real or may be explained by the fact that JSN/JSW is an indirect measure of cartilage volume [7]. In the hip, the joint space is largely made up of cartilage [21], however, in the knee, in addition to cartilage volume, other factors such as meniscal tear/extrusion and cartilage defects [22, 23] contribute to progression of JSN and could weaken the association. At present, MRI is the only imaging modality that can delineate articular cartilage directly and noninvasively [6], yet no such correlation has been reported. Therefore the aim of this study was to confirm the association of the hip and knee cartilage obtained by radiographic means and compare the data with those from MRI in a randomly selected older population.

Materials and methods

Subjects

This study was conducted as part of the Tasmanian Older Adult Cohort (TASOAC) Study, a prospective, population-based study that was initiated in 2002 and was aimed at identifying the environmental, genetic and biochemical factors associated with the development and progression of OA at multiple sites (hand, knee, hip and spine). Subjects between the ages of 50 and 81 years were randomly selected from the roll of electors in southern Tasmania (population 229 000), a comprehensive population listing, using sex-stratified simple random sampling without replacement (response rate 57%). Persons were excluded if they were institutionalized or had contraindications to MRI. The study was approved by the Southern Tasmanian Health and Medical Human Research Ethics Committee and written informed consent was obtained from all participants. The current study consisted of a subsample of 151 TASOAC participants who had both a hip and a knee MRI scan at the baseline.

Imaging

Hip: X-ray determination and assessment

Anteroposterior radiographs of the pelvis with weight bearing and with both feet in 10° of internal rotation were obtained. Radiographic features of axial JSN, superior JSN and osteophytes of the right hip were graded on a 4-point scale (range 0–3, where 0 = no disease and 3 = most severe disease) using the Altman atlas [24]. Each score was determined by consensus between two readers who were blinded to the subject's cartilage volume and who simultaneously assessed the radiograph with immediate reference to the atlas. The total radiographic OA score was computed by summing the JSN scores; the total radiographic OA score was used as an indicator of the radiographic severity of hip OA. The intraobserver reliability was assessed in 40 subjects with intraclass correlations (ICCs) of 0.60–0.87.

Knee: X-ray determination and assessment

A standing anteroposterior semi-flexed view of the right knee with 15° of fixed knee flexion was performed. Radiographs were assessed using the Altman atlas [24], in which a scale of 0–3 was used to score the medial and lateral JSN. Each score was determined by consensus of two readers who simultaneously assessed the radiograph with immediate reference to the atlas. Intraobserver repeatability was assessed in 40 subjects with an interval of at least 1 week between the two measurements. ICCs ranged from 0.65 to 0.85. The presence of radiographic osteoarthritis was defined as any score $\geqslant 1$ for JSN or osteophytes. Total knee JSN was calculated as medial JSN + lateral JSN.

Hip MRI femoral cartilage volume determination and assessment

The MRI of the right hip was performed on all 151 individuals in the sagittal plane using a 1.5 T whole-body magnetic resonance unit (Picker, Cleveland, OH, USA) with a phased-array flex coil. The following image sequence was used: a T1-weighted fat-suppressed three-dimensional (3D) gradient-recalled acquisition in the steady state, flip angle 55°, repetition time 58 ms, echo time 12 ms, field of view 20 cm, 60 partitions, 512 × 512 pixel matrix, acquisition time 11 min 56 s, one acquisition. Sagittal images were obtained at a partition thickness of 1.5 mm and an in-plane resolution of 0.39 mm × 0.39 mm (512 × 512 pixels).

Femoral head cartilage volume was measured by one reader and determined by means of image processing at an independent workstation using the software program Osiris (version 3.5; Geneva University Hospital, Geneva, Switzerland) as previously described [25]. The image data were transferred to the workstation and an isotropic voxel size was then obtained by a trilinear interpolation routine. The volume of the femoral head cartilage was isolated from the total volume by manually drawing disarticulation contours around the cartilage boundaries on each image section. These data were then resampled by bilinear and cubic interpolation for the final 3D rendering. The volume of the femoral head cartilage was determined by summing all the pertinent voxels within the resultant binary volume. As previously reported, intraobserver reliability was assessed in 100 subjects on the same images with at least a 1-week interval between measures, and the coefficient of variation (CV) was 2.5% [21].

Knee MRI cartilage volume determination and assessment

As for the hip, the knee MRI was performed on the right leg of all 151 individuals in the sagittal plane of the above mentioned 1.5 T whole-body magnetic resonance unit using a commercial transmit/receive extremity coil. Image sequences included a T1-weighted fat saturation 3D gradient-recalled acquisition in the steady state, flip angle 30°, repetition time 31 ms, echo time 6.71 ms, field of view 16 cm, 60 partitions, 512 × 512 pixel matrix, acquisition time 5 min 58 s, one acquisition; sagittal images were obtained at a slice thickness of 1.5 mm without an interslice gap.

Knee tibial cartilage volume was determined by means of image processing on an independent workstation using Osiris software (University of Geneva, Geneva, Switzerland) as previously described [26, 27]. The volumes of individual cartilage plates (medial tibia and lateral tibia) were isolated from the total volume by manually drawing disarticulation contours around the cartilage boundaries on a section-by-section basis. These data were then resampled by means of bilinear and cubic interpolation (area of 312 mm × 312 mm and 1.5 mm thickness, continuous sections) for the final 3D rendering. The CV was 2.1% for the medial tibia and 2.2% for the lateral tibia, as previously described [26].

Knee femoral cartilage volume was determined by means of image processing on an independent workstation using Cartiscope (ArthroLab, Montreal, Quebec, Canada), as previously described [28–30]. In brief, the segmentation of the cartilage–synovial interfaces was carried out with the semi-automatic method under reader supervision and with corrections when needed. Cartilage volume was evaluated directly from a standardized view of 3D cartilage geometry as the sum of elementary volumes. The CV was about 2% [29]. The cartilage volume assessment was done for the medial and lateral condyles delineated by the Blumensaat's line [30]. Total cartilage volume was calculated as tibial cartilage volume + femoral cartilage volume.

Statistical analysis

Differences in means and proportions were compared using *t*-tests and χ^2 tests as appropriate when examining demographic, cartilage volume and JSN data. Correlation analysis was performed on the ranks of variables to summarize the association between the knee and the hip JSN. Pearson's and partial correlation analyses were used to summarize the association between knee and hip cartilage volume. Multivariate analyses in both instances were adjusted for age, sex, height and weight. A *P*-value <0.05 (two-tailed) was considered statistically significant. All statistical analyses were performed on Intercooled Stata 12.0 for Windows (StataCorp LP).

Results

A total of 151 subjects (79 men and 72 women) between the ages of 50 and 81 years were included in this study. The characteristics of this study population compared with the rest of TASOAC are as follows: (TASOAC first) number of participants = 1099 *vs* 151; age = 62.9 *vs* 63.4 years, $P = 0.433$; sex (male) = 49% *vs* 52.3%, $P = 0.361$; BMI = 28.0 *vs* 27.4, $P = 0.139$; knee radiographic OA = 59% *vs* 66%, $P = 0.08$.

The characteristics of the study population are presented in Table 1 split by median hip cartilage volume (5227 mm^3). There were a higher proportion of males in those with higher hip cartilage volume. The participants with higher hip cartilage volume were also older, had higher tibial, femoral and total knee cartilage volume and had lower hip JSN score, as previously reported [21]. Lateral and total knee JSN scores were also slightly higher in those with higher hip cartilage volume, but the difference between the two groups was not significant. In general, medial JSN (60%) was more common than lateral JSN (23%). This was expected, as the medial compartment is affected more often by OA than any other tibiofemoral compartment in clinical studies [31, 32]. In the participants who had any JSN, medial JSN scores (grade 0 = 40%, 1 = 46%, 2 = 11%, 3 = 3%) were also higher on average than lateral JSN scores (grade 0 = 77%, 1 = 19%, 2 = 3%, 3 = 1%), and hence there was very little variation between medial and total JSN correlations.

Table 2 describes the correlation coefficients for the relationship between knee and hip JSN. In unadjusted analysis, both medial and total knee JSN were positively, but weakly, associated with superior hip JSN. After adjusting for age, sex, height and weight, the associations persisted. None of the knee JSN parameters were significantly associated with axial hip JSN in unadjusted or adjusted analyses.

Table 3 describes the correlation coefficients for the association between knee and hip cartilage volume. In unadjusted analysis, all the knee cartilage volume measures were positively associated with hip cartilage volume. After adjustment for age, sex, height and weight, the associations decreased in magnitude but remained significant apart from medial femoral knee cartilage volume ($P = 0.227$). Hip and knee cartilage volume were categorized into quartiles to compare cartilage volume and JSN correlations, as JSN is an ordinal variable with four grades, whereas cartilage volume is a continuous variable. The correlations weakened after categorizing cartilage volume into quartiles, but they were still significant (total knee: $r = 0.30$, $P = 0.024$). Fig. 1 describes the adjusted partial correlation analysis between hip cartilage volume and total knee cartilage volume.

Discussion

This is the first article to examine the association between hip and knee cartilage volume, measured quantitatively, using MRI. Knee cartilage volume measures showed a consistent, positive association with femoral hip cartilage volume. The association between hip and knee MRI-based cartilage volume was stronger than radiographic-based assessment of JSN.

Table 1 Characteristics of participants by hip cartilage volume

	Hip cartilage volume <mean (5297 mm^3) ($n = 76$)	Hip cartilage volume ⩾mean ($n = 75$)	*P*
Age, years	62.0 (7.1)	65.0 (8.4)	0.019
Males, %	25	80	<0.001
Medial tibial cartilage volume, mm^3	2023 (432)	2627 (428)	<0.001
Lateral tibial cartilage volume, mm^3	2427 (501)	3116 (629)	<0.001
Total tibial cartilage volume, mm^3	4450 (843)	5743 (1023)	<0.001
Medial femoral cartilage volume, mm^3	3449 (830)	4289 (1018)	0.001
Lateral femoral cartilage volume, mm^3	3699 (835)	4930 (845)	<0.001
Total femoral cartilage volume, mm^3	7148 (1650)	9129 (1740)	<0.001
Total knee cartilage volume, mm^3	11 396 (2196)	15 233 (2766)	<0.001
Percentage with medial knee JSN	60	59	0.917
Percentage with lateral knee JSN	19	28	0.175
Percentage with total knee JSN	61	72	0.318

Values are mean (S.D.) or percentage. *P*-values determined by *t*-test or χ^2 test (where appropriate).

Table 2 Correlation between hip and knee joint space narrowing

Knee JSN site	Unadjusted (hip superior JSN)		Adjusted[a] (hip superior JSN)		Unadjusted (hip axial JSN)		Adjusted[a] (hip axial JSN)	
	r	*P*	*r*[a]	*P*	*r*	*P*	*r*[a]	*P*
Medial JSN	0.21	0.010	0.19	0.024	0.10	0.211	0.11	0.184
Lateral JSN	0.02	0.844	0.03	0.746	−0.01	0.898	−0.01	0.902
Total JSN	0.20	0.014	0.19	0.025	0.08	0.326	0.10	0.253

[a]Adjusted for age, sex, height and weight.

Table 3 Correlation between hip and knee cartilage volume

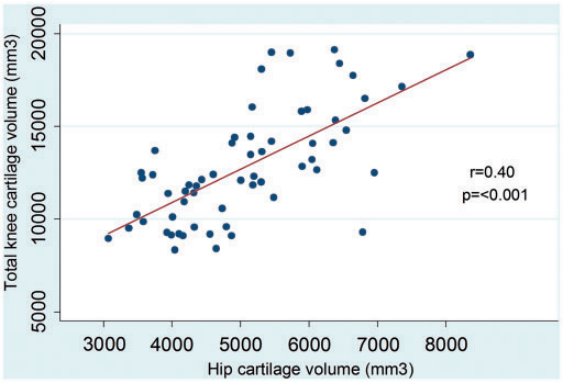
Site	Unadjusted (hip cartilage volume)		Adjusted[a] (hip cartilage volume)		Adjusted[b] (hip cartilage volume)	
	r	*P*	*r*	*P*	*r*	*P*
Medial tibial	0.56	<0.001	0.26	0.002	0.22	0.009
Lateral tibial	0.52	<0.001	0.24	0.003	0.20	0.015
Total tibial	0.59	<0.001	0.30	<0.001	0.31	<0.001
Medial femoral	0.48	<0.001	0.16	0.227	0.06	0.651
Lateral femoral	0.64	<0.001	0.35	0.008	0.36	0.007
Total femoral	0.59	<0.001	0.27	0.041	0.11	0.436
Total knee	0.66	<0.001	0.40	0.002	0.30	0.024

[a]Adjusted for age, sex, height and weight. [b]Adjusted for age, sex, height and weight with hip and knee cartilage volumes split in quartiles.

There was no or a weak correlation, depending on the site, between hip and knee JSN. Correlations for the hip were stronger for superior JSN compared with axial JSN. Only medial and total knee JSN (medial and lateral combined) showed a significant correlation with superior JSN in adjusted analysis. The correlations we saw between hip and knee cartilage volume were all stronger than the correlations between hip and knee JSN. Total knee cartilage volume (tibial and femoral combined) most strongly correlated with hip volume.

These radiographic results are consistent with the literature. Kinds *et al.* [20] used digital radiography to examine the association between hip and knee JSW and found a stronger correlation ($r = 0.29$), perhaps due to more accurate imaging. In another similar study, Sayre *et al.* [19] used plain radiography to quantify the association of OA in one

FIG. 1 Correlation between hip cartilage volume and total knee cartilage volume.



Line of best fit, partial correlation coefficient (*r*) and *P*-value were adjusted for age, sex, height and weight.

knee or hip joint with other knee or hip joints. They also found a weak but mostly statistically significant association between ipsilateral hip and knee JSN.

In contrast, correlations for cartilage volume in our study were all stronger than for radiographic JSN. Possible reasons for this may be the fact that radiographic JSN is an ordinal measure and estimates cartilage volume indirectly, as it can only delineate the bone [7]. MRI has substantial advantages over radiography, as its 3D coverage of anatomical structures allows quantitative measurement of cartilage morphology (i.e. thickness, volume and surface areas) [33, 34], resulting in less measurement error and yielding more precise results. Other factors besides cartilage, such as meniscal extrusion [22, 23, 35, 36] and partial or complete rupture of the anterior cruciate ligament (ACL) [36–41], contribute to the progression of knee JSN in OA. Radiography cannot detect these changes directly and that weakens the knee JSN associations compared with cartilage volume measurements.

This study suggests that there is commonality between cartilage volume at the hip and knee joints. Several studies have shown that OA is often generalized and affects multiple joints. In a post-mortem bone study, Rogers *et al.* [42] confirmed the hypothesis that OA is caused primarily by a systemic predisposition. Other studies have shown an association between hand and knee OA [8, 18, 43, 44], and to lesser extent with hip [9, 44] and spine OA [45]. From the above studies we can infer that the knee is part of generalized OA, whereas the evidence is not that strong in the case of the hip. Our results support the notion that hip OA can be a part of generalized OA.

One of the strengths of our study is that different readers scored radiographs and MRI scans, removing a potential source of bias in the reading of these scans. Our study also has potential limitations. First, this was a cross-sectional study and we cannot make inferences about causal or longitudinal associations. Second, this study included only ipsilateral data and as a result cannot examine the strength of association between cartilage volume in diagonal joints (right hip and left knee or left hip and right knee).

In conclusion hip and knee cartilage volume are more strongly associated than hip and knee radiographic JSN, suggesting the commonality of cartilage volume at these two sites. The weaker radiographic association may reflect less measurement error with MRI or the contribution of multiple structures to joint space in the knee.

Rheumatology key messages

- The association between hip and knee cartilage volume suggests commonality between the two sites for OA.
- The hip joint may be a part of generalized OA, but longitudinal studies are required to establish that definitively.

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H.I.K. carried out analysis and interpretation of data, prepared the initial manuscript draft and completed manuscript revisions. D.A. was responsible for data cleaning and management, data interpretation and drafting of the manuscript. G.Z. was responsible for the measurement of hip cartilage volume and drafting of the manuscript. C.D. was responsible for drafting of the manuscript. J.-P.P., J.M.P. and their team were responsible for the measurement of femoral cartilage volume and drafting of the manuscript. L.B. was responsible for data analysis and drafting of the manuscript. F.C. and G.J. were responsible for protocol development, data acquisition and drafting of the manuscript.

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