Comparison between patella cartilage volume and radiological assessment of the patellofemoral joint

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Abstract

Objectives

There is no information on how patella cartilage relates to the radiological grade of individual features of patellofemoral osteoarthritis (osteophytes or joint space narrowing) which have been used in most epidemiological and clinical studies. In this study we compared patella cartilage volume as measured by magnetic resonance imaging (MRI) with radiological assessment of the patellofemoral joint.

Methods

157 subjects with specific features of patellofemoral osteoarthritis (osteophytes and joint space narrowing) ranging from grade 0-3 were examined (age 62 ± 10 years, 62% female). Each subject had skyline and lateral patellofemoral radiographs performed. Patella cartilage volume was determined by processing images acquired in the sagittal plane using T1-weighted fat saturated MRI at an independent work station.

Results

Grade of joint space narrowing (JSN) as measured on skyline and lateral patellofemoral radiographs was inversely associated with patella cartilage volume. After adjusting for age, gender and body mass index, for every increase in grade of skyline JSN (0-3), the patella cartilage volume was reduced by 411 mm^3. For every increase in lateral patellofemoral JSN grade (0-3), the adjusted patella cartilage volume was reduced by 125 mm^3. The relationship was stronger for patella cartilage volume and skyline JSN ($r = -0.54$, $p < 0.001$) than for lateral patellofemoral JSN ($r = -0.16$, $p = 0.015$). There was no significant association between patella cartilage volume and osteophytes measured on skyline or lateral radiographs.

Conclusions

There is a significant negative association between patella cartilage volume and JSN, but not osteophytes. This association was strongest for the skyline rather than lateral radiographs. Longitudinal studies will be needed to determine the role of patella cartilage measurement in assessing progression of patellofemoral osteoarthritis.

Key words

Osteoarthritis, patellofemoral compartment, knee cartilage volume.

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Introduction

Osteoarthritis (OA) is a common cause of disability in people aged over 65 years (1). It has been shown that symptomatic knee OA may often be related to patellofemoral disease (2, 3). Indeed, isolated patello-femoral OA may be so debilitating that total joint replacement surgery is performed (4). Recent studies have suggested that skyline radiographs are the optimum radiological method for measuring patellofemoral OA (3, 6, 7).

There has been increasing interest in the use of magnetic resonance imaging (MRI) in the measurement of knee cartilage volume as a possible outcome measure in arthritis (8-11). Measurement of patella cartilage has been shown to be a valid measure of cartilage volume when MRI cartilage volume is compared to anatomical dissection and to be reproducible with coefficient of variations of less than 5% (8-11). However, little attention has been focussed on the role of MRI in measurement of disease in patellofemoral OA.

There are a number of potential advantages of measuring patella cartilage volume. This measurement provides a direct measure of joint cartilage, rather than an indirect measure as with radiographs. Since the whole three-dimensional structure is examined, the potential problem of reselecting identical locations in follow-up knee radiographs is reduced. Small positional changes from one examination to the next may affect the reproducibility of joint space narrowing, particularly in longitudinal studies and this should be minimized by measuring the whole three-dimensional structure.

The work carried out to date suggests that MRI will provide a very sensitive and reproducible method for measuring cartilage. There is no information on how patella cartilage volume relates to radiological grade of individual features of patellofemoral OA which has been used in most epidemiological and clinical studies (12). This will be useful in relating studies using patella cartilage to the available body of patellofemoral OA literature. It is likely that both radiological and MRI assessment of joints become complementary tools in investigating OA. In this study, we compared patella cartilage volume as measured by magnetic resonance imaging (MRI) with radiological assessment of the patellofemoral joint.

Patients and methods

157 subjects aged over 40 years undergoing studies on osteoarthritis within our department were included in this study. Subjects were excluded if any other form of arthritis was present, if there were contra-indications to MRI (e.g. pacemaker, cerebral aneurysm clip, cochlear implant, presence of shrapnel in strategic locations, metal in the eye, and claustrophobia), inability to walk 50 feet without the use of assistive devices, hemiparesis of either lower limb, planned total knee replacement. Weight was measured to the nearest 0.1kg (shoes and bulky clothing removed) using a single pair of electronic scales. Height was measured to the nearest 0.1 cm (shoes removed) using a stadiometer. Body mass index (BMI) (weight/height^2 kg/m^2) was calculated. Each subject had an MRI performed on one knee. This was either their dominant knee (defined as the lower limb from which they step off when walking) or the knee causing them symptoms with least severe osteoarthritis. Patella cartilage volume was determined by means of image processing on an independent workstation as previously described (13). All MRI in this study were measured by a single trained observer. Fifty subjects who covered the range of patellofemoral OA were assessed for reproducibility of the method. Each MRI cartilage volume was measured by the reader without knowledge of the severity of patellofemoral OA in the study subjects. The MRI patella cartilage volume was remeasured one week later. The coefficient of variation (CV) was 2.1% for patella cartilage volume (13).

The following radiographic views of the patellofemoral joint were obtained: (i) a standing lateral (medio-lateral) view in 30º flexion and (ii) a skyline (infero-superior) view in 45º flexion using a perspex positioning wedge with the subject supine. All radiographs were independently assessed by two trained

observers using an atlas (14). The observers were blind to the clinical findings. The radiological features of OA in the patello-femoral joint (PFJ) were graded on a four-point scale (0-3) for both individual features of osteophytes and joint space. The intraobsever variability was: skyline osteophytes (0.84), skyline joint space narrowing 0.76, lateral osteophytes (0.82), lateral joint space narrowing 0.75. The interobsever variability was: skyline osteophytes (0.83), skyline joint space narrowing 0.75, lateral osteophytes (0.77), lateral joint space narrowing 0.75.

Statistical analysis

Linear regression was used to examine the relationship between patella cartilage volume and radiological features of patellofemoral osteoarthritis (joint space narrowing and ostephytes) in univariate analyses. Multiple linear regression was then used to adjust for the effect of age, gender and body mass index (BMI) on patella cartilage volume. Results are presented as regression coefficients that represent differences in patella cartilage volume per unit change in radiological grade, while other factors are held constant (controlled for). A robust variance estimator was used to provide valid standard error estimates when non-constant variability was encountered (15).

In order to present a two-dimensional graphical display of the relationship between cartilage volume and radiological features after controlling for age, gender and BMI, we employed the following two-step procedure. At the first step, residuals from the regression of cartilage volume on age, gender and BMI were computed which represent the component of cartilage volume not explained by age, gender and BMI. To aid in graphical displays, the mean cartilage volume of 2154 mm^3 was added to all residuals, and we term these quantities the "adjusted" cartilage volumes. Note that the addition of a fixed number to all residuals does not change their properties. In the second step we examined the relationship of the adjusted cartilage volumes with skyline and lateral osteophytes and narrowing using boxplots and correlation coefficients.

Results

The characteristics of the study population, including the prevalence of radiological features of patellofemoral joint disease, are presented in Table I. Univariate analyses showed that joint space narrowing as measured on skyline and lateral patellofemoral radiographs was inversely associated with patella cartilage volume. This inverse relationship was strengthened following adjustment for age, gender and body mass index. After adjusting for these confounders, for every increase in skyline joint space narrowing (JSN) grade (0 to 3), the patella cartilage volume was significantly reduced by 411 mm^3. After adjusting for the above confounders, for every increase in grade (0-3) of lateral patellofemoral JSN, the patella cartilage volume was significantly reduced by 125 mm^3. The relationship was stronger for patella cartilage volume and grade of skyline JSN than for the grade of lateral patellofemoral JSN. In contrast to the inverse relationship between patella cartilage volume and grade of JSN, there was a weak, but not significant, positive association between patella cartilage volume and osteophyte grade measured on both the skyline and lateral radiographs (Table II).

The correlations between patella cartilage volumes and radiographic patellofemoral OA were: skyline JSN ($r = -0.54$, $p < 0.001$), skyline osteophytes ($r = 0.04$, $p = 0.62$), lateral JSN ($r = -0.16$, $p = 0.015$), lateral patellofemoral osteophytes ($r = 0.10$, $p = 0.26$). A stronger relationship existed between adjusted

Table I. Characteristics of the participants.

	(n = 157)
Age* (years)	62 (10)
% Females	62%
Body mass index* (kg/m^2)	28.7 (5.5)
% Subjects with skyline osteophyte score ≥ 1	62%
% Subjects with skyline joint space narrowing score ≥ 1	45%
% Subjects with lateral patellofemoral osteophyte score ≥ 1	65%
% Subjects with lateral patellofemoral joint space narrowing score ≥ 1	34%
Patella cartilage volume* (ml)	2.15 (0.62)

*Mean (SD)

Table II. Relationship of patella cartilage volume and radiological features of osteoarthritis at the patellofemoral joint.

	Univariate analysis Regression coefficient*	Multivariate analysis** Regression coefficient***	95% CI	p-value	Correlation coefficent ****
Skyline joint space narrowing	-419	-411	(-503, -319)	< 0.001	-0.54
Skyline osteophytes	83	24	(-73, 121)	0.62	0.041
Lateral joint space narrowing	-120	-145	(-262, -28)	0.015	-0.16
Lateral osteophytes	54	66	(-50,183)	0.26	0.10

*Change in patella cartilage volume per unit increase in radiological grade.
**Multivariate analysis with age, gender and BMI in the regression equation
***Change in patella cartilage volume per unit increase in radiological grade with age, BMI and gender held fixed.
****Correlation between radiological features and residuals from regression of patella cartilage on age, gender, BMI.

patella cartilage and radiological grade of joint space narrowing than with osteophytes. There was also a stronger association between adjusted patella cartilage and skyline joint space narrowing than with lateral patellofemoral joint space narrowing. Boxplots showing the relationship between radiological measure of patellofemoral osteoarthritis and patella cartilage volume after controlling for age, gender and BMI are presented in Figure 1.

Discussion

We have shown a significant negative association between patella cartilage volume and the grade of joint space narrowing as measured on both the skyline and lateral views of the patellofemoral joint. This association was strongest for the skyline views compared to the lateral views. There was no association between patella cartilage volume and osteophytes measured on either the skyline or the lateral patella radiographs.

No previous studies have examined patella cartilage volume in individual subjects as they relate to the radiological grade of features of patellofemoral OA. We showed that there is a significant moderate negative association between patella cartilage volume and grade of joint space narrowing measured either on the skyline or the lateral patellofemoral views, but not with osteophytes. This is not surprising given that the measurement of joint space narrowing is being used as a surrogate measure of the structure of the joint cartilage and MRI allows us to measure this directly.

Our study, which has measured patella cartilage directly, suggests that there is a stronger relationship between skyline joint space narrowing and patella cartilage volume than with lateral patellofemoral radiographs. This is consistent with the growing body of evidence suggesting that skyline radiographs are better for assessing the patellofemoral joint (3,6, 7). Although reproducibility of both views for detecting osteophytes has been shown to be high, skyline views performed much better than lateral views both within and between observers for detecting joint space narrowing (6). When the two radiographic methods were compared for their sensitivity for the detection of patellofemoral osteoarthritis progression, it was possible to observe significant joint space loss over time on the skyline view that was not apparent on the lateral view (6). This is consistent with another study that showed no significant change in joint space narrowing in subjects with OA over 3 years using lateral radiographs (16).

There are a number of potential limitations in using MRI for cartilage volume estimates. The accurate delineation of articular cartilage depends on high contrast relative to adjacent tissues. We therefore used a previously validated fat-suppressed gradient echo sequence (11, 13). Furthermore, as has previously been recommended (10), in order to improve in-plane resolution we used a matrix of 512 x 512 pixels, resulting in an in-plane resolution of 0.31 x 0.31

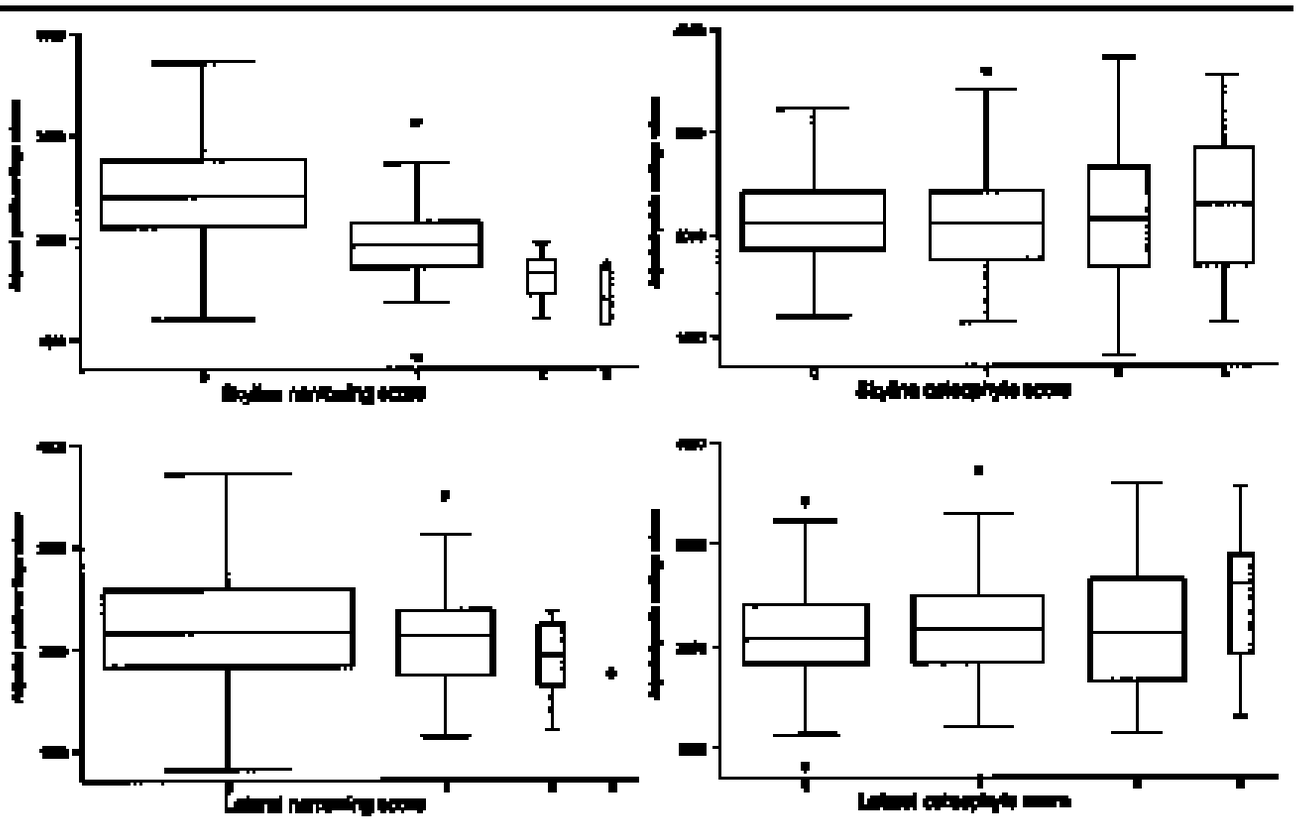

Fig. 1. Boxplots of patella cartilage volume versus skyline and lateral patellofemoral radiological grade, after controlling for age, gender and BMI. The width of each box is proportional to the number of observations on which it is based.

mm. The reproducibility of our patella measurements is high, with little partial volume effects in the measurement of patella cartilage with the 1.5 mm slice width used (11, 13). Our population consisted of subjects taking part in studies of osteoarthritis and not a randomly selected population. However, these individuals had severity levels of patellofemoral joint osteoarthritis ranging from no disease to severe disease. This has allowed us to examine the respective patella cartilage volume for each grade of patellofemoral osteoarthritis. Subgroup analyses of males and females separately did not alter the associations we found (data not shown). Nevertheless, these results will need to be confirmed in a population-based sample.

In this study we only measured the patella cartilage as a surrogate measure of what is happening to joint cartilage in the patellofemoral joint. Joint space narrowing measures both the femoral and patella cartilage. However, there are potential problems in using femoral cartilage since this cartilage forms part of three joints, the medial and lateral tibiofemoral joints and the patellofemoral joint. There are no simple, discrete boundaries that allow anatomical definition of the component of the femoral cartilage that takes part in the patellofemoral joint as opposed to the other joints. For this reason, it is a very attractive option to use a simple, well-defined anatomical structure such as the patella cartilage as a surrogate measure of what is happening to joint cartilage in the patellofemoral joint. In an analogous situation, we have shown that tibial and femoral cartilage volumes correlate in both the medial and lateral tibiofemoral joints, suggesting that measuring tibial cartilage alone may be a useful marker of cartilage change in the medial and lateral tibiofemoral joints (17). The significant association we found between patella cartilage volume and joint space narrowing in this study further supports this.

Studies investigating joint cartilage in healthy subjects or those with very early disease have been limited by the lack of tools to assess joint cartilage non-invasively. The role of MRI in assessment of the patellofemoral joint is still in the early stages. However, MRI cartilage volume provides a potential method for investigating factors that influence the amount of cartilage in healthy individuals, where radiographs show only very early OA or are even normal (13,18). Our data suggest that up to 20% of patella cartilage is lost by the time an individual has joint space narrowing of grade 1. There are also a number of potential advantages of MRI over radiographic assessment of joints for studies of disease progression, especially in early disease. MRI measures cartilage directly, rather than indirectly as with radiographs. MRI measurement may be less subject to positional variation since the three-dimensional structure can be measured with thin image separations (10). MRI cartilage volume may be more sensitive than radiographic assessment of joint cartilage so that small changes can be measured over time using much smaller numbers of subjects (10). However this will need to be investigated in longitudinal studies.

In summary, we have shown a significant negative association between patella cartilage volume and joint space narrowing, but not osteophytes, as measured on both the skyline and lateral views of the patellofemoral. This association was strongest for the skyline views compared to the lateral views, where up to 20% of patella cartilage is lost by the time a subject has grade 1 joint space narrowing. This suggests that measurement of patella cartilage volume alone may be a useful measure of joint cartilage at the patellofemoral joint. Whether cartilage measurement alone will be sufficient as a measure of disease progression in OA remains to be proven. Longitudinal studies will be needed to determine the role of patella cartilage in measuring progression of patellofemoral OA.

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References

1. FELSON DT, NAIMARK A, ANDERSON J, KAZIS L, CASTELLI W, MEENAN RF: The prevalence of knee osteoarthritis in the elderly: The Framingham Osteoarthritis Study. *Arthritis Rheum* 1987; 30: 914-18.
2. MCALINDON TE, SNOW S, COOPER C, DIEPPE PA: Radiographic patterns of knee osteoarthritis in the community: The importance of the patellofemoral joint. *Ann Rheum Dis* 1993. 51: 844-9.
3. LEDINGHAM J, REGAN M, JONES A,DOHERTY M: Radiographic patterns and associations of osteoarthritis of the knee in patients referred to hospital. *Ann Rheum Dis* 1993; 52: 520-6.
4. LASKIN RS, VAN STEIJN M: Total knee replacement for patients with patellofemoral arthritis. *Clin Orthop* 1999; 367: 89-95.
5. JONES A, LEDINGHAM J, MCALINDON TE: Radiographic assessment of patellofemoral osteoarthritis. *Ann Rheum Dis* 1993; 52:655-8.
6. LANYON P, JONES A, DOHERTY M: Assessing progression of patellofemoral osteoarthritis:A comparison between two radiographic methods. *Ann Rheum Dis* 1996; 55: 875-879.
7. CICUTTINI FM, BAKER J, SPECTOR TD: Choosing the best method for radiological assessment of patellofemoral osteoarthritis. *Ann Rheum Dis* 1996; 55: 134-6.
8. PETERFY CG, VAN DIJKE CF, JANZEN DL *et al*.:Quantification of articular cartilage in the knee with pulsed saturation transfer subtraction and fat-suppressed MR imaging: Optimization and validation. *Radiology* 1994; 192: 485-91.
9. SITTEK H, ECKSTEIN F, GAVAZZENI A *et al*.: Assessment of normal patella cartilage volume and thickness using MRI; An analysis of currently available pulse sequences. *Skeletal Radiology* 1996; 25: 55-62.
10. ECKSTEIN F, WESTHOFF J, SITTEK H *et al*.: *In vitro* reproducibility of three-dimensional cartilage volume and thickness measurements with MRI imaging. *Am J Radiol* 1998; 170: 593-7.
11. CICUTTINI F, FORBES A, MORRIS K, DARLING S, BAILEY M, STUCKEY S: Gender differences in knee cartilage volume as measured by magnetic resonance imaging. *Osteoarthritis Cart* 1999; 7: 265-71.
12. LEQUESNE M, BRANDT K, BELLAMY N *et al*.: Guidelines for testing slow acting drugs in osteoarthritis. *J Rheumatol* 1994; (Suppl. 41) 21: 65-73.
13. CICUTTINI FM, WLUKA A, WANG YY: The determinants of change in patella cartilage volume in osteoarthritic knees. *J Rheumatol* 2002; 29: 2615-9.
14. BURNETT S, HART DJ, COOPER C, SPECTOR TD: *A Radiographic Atlas of Osteoarthritis*. 1994, London, Springer-Verlag.
15. WHITE A: A heterskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica* 1980; 48: 817-38.
16. SPEAKE SC, SZEBENYI B, DIEPPE PA: Quantitative serial assessment of patellofemoral joint osteoarthritis from lateral knee radiographs. *Osteoarthritis Cart* 1995; 3

(Suppl. A): 89-96.
17. CICUTTINI F, WLUKA A, WANG YY, DAVIS S, HANKIN J, EBELING P: Compartment differences in knee cartilage volume in healthy adults. *J Rheumatol* 2002: 29: 554-6.
18. WLUKA AE, DAVIS S, BAILEY M, STUCKEY S, CICUTTINI F: Users of oestrogen replacement therapy have more knee cartilage than non-users. *Ann Rheum Dis* 2001; 60: 332-6.