Osteoarthritis and Cartilage (2008) **16,** 131–135

doi:10.1016/j.joca.2007.08.002

Osteoarthritis and Cartilage

International Cartilage Repair Society

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Brief report
Femoral sulcus angle and increased patella facet cartilage volume in an osteoarthritic population[1]

M. Davies-Tuck B.Biomed. Sci. (Hons.)†, A. J. Teichtahl B.Physio. (Hons.)†, A. E. Wluka M.B.B.S., F.R.A.C.P., Ph.D.†‡, Y. Wang Ph.D.†, D. M. Urquhart B.Physio. (Hons.) Ph.D.†, J. Cui B.Sc., MMed., Ph.D.† and F. M. Cicuttini M.B.B.S., F.R.A.C.P., Ph.D.†*

† *Department of Epidemiology and Preventive Medicine, Monash University, Central and Eastern Clinical School, Alfred Hospital, Melbourne, Vic 3004, Australia*

‡ *Baker Heart Research Institute, AMREP, Commercial Road, Melbourne, Vic 3004, Australia*

Summary

Objective: The patellofemoral joint is an example of an incongruent articulation commonly affected by osteoarthritis (OA). The relationship between femoral sulcus angle and the development and progression of patellofemoral OA is unclear. The aim of this study was to examine the relationship between the femoral sulcus angle at baseline and patella cartilage volume at baseline and at 2-year follow-up among community based adults with established knee OA.

Methods: One hundred subjects had magnetic resonance imaging of their symptomatic knee at baseline and at 2-year follow-up. From these images, patella cartilage volume was determined. Radiographic skyline views of the patellofemoral joint were taken at baseline to measure the femoral sulcus angle.

Results: For every 1° increase in the femoral sulcus angle (i.e., as the sulcus angle became more shallow) there was an associated 9.1 mm^3 (95% CI 3.1, 15.0) increase in medial patella cartilage volume at baseline ($P = 0.003$). There was a similar trend that approached statistical significance between the femoral sulcus angle and the lateral patella facet cartilage volume at baseline ($P = 0.09$). There was no association between the femoral sulcus angle at baseline and the change in patella cartilage volume over 2 years in either patellofemoral compartment.

Conclusion: These results infer that the femoral sulcus angle is a cross-sectional determinant of the amount of patella cartilage, but is not a major determinant of the annual change of patella cartilage volume among people with knee OA. These data suggest that a shallower sulcus in the context of established OA may be an advantageous anatomical variant. Further longitudinal studies are required to determine the role of the femoral sulcus angle in OA.

Key words: Sulcus angle, Patella cartilage, Patella facets, Patellofemoral osteoarthritis.

Introduction

The patellofemoral joint, which is formed by the articulation between the irregularly shaped under-surface of the patella and the femoral trochlear groove, is one example of an incongruent joint that is commonly affected by painful and disabling pathological processes such as osteoarthritis (OA)[1]. Incongruent joints sacrifice stability for mobility, and as a result, are commonly affected by pathological processes. In particular, the larger lateral patellofemoral compartment is most commonly affected by OA[2–4].

Of the bony landmarks along the trochlear groove, the femoral sulcus angle, which forms an articular surface for the patella between the medial and lateral femoral condyles, has been recognised as an important factor in patellofemoral stability[2,5]. Nevertheless, no study has examined the femoral sulcus angle in the context of patellofemoral OA. One reason for this paucity of data may have arisen because of the difficulty in obtaining valid and reliable measures of patellofemoral joint structure, namely cartilage volumes that are sensitive to change. Radiographic quantitation of patellar cartilage, approximated by radiographic joint space, is unreliable when assessed longitudinally by either the skyline or lateral views, since these views may be affected by knee position, patellar tilt and subluxation[6,7]. Moreover, indirect examination of the radiographic joint space width as a surrogate for patellofemoral cartilage has proven to be problematic, unless joint space narrowing is very severe[8]. In contrast, magnetic resonance imaging (MRI) enables patellar cartilage to be directly assessed[9–11]. Another reason may also be that accurate measures of sulcus angle from

[1]This study was supported by the National Health and Medical Research Council (980914). Drs Wluka, Wang and Urquhart are the recipients of National Health and Medical Research Council Post Doctoral Fellowships (317840, 465142 and 284402, respectively).

*Address correspondence and reprint requests to: Professor Flavia Cicuttini, Department of Epidemiology and Preventive Medicine, Monash University, Central and Eastern Clinical School, Alfred Hospital, Melbourne, Vic 3004, Australia. Tel: 61-3-9903-0555; Fax: 61-3-9903-0556; E-mail: flavia.cicuttini@med.monash.edu.au

Received 1 May 2007; revision accepted 4 August 2007.

radiographs are problematic due to their dependence on the degree of knee flexion, and only one group has previously described three-dimensional (3D) analysis of the sulcus angle by using an open MRI scanner[12].

The aim of this study was to examine whether the femoral sulcus angle is a determinant of compartmental patella cartilage volume at baseline and change in compartmental volume in a population with OA over 2 years.

Methods

STUDY PARTICIPANTS

Subjects with knee OA were recruited by advertising through local newspapers and the Victorian branch of the Arthritis Foundation of Australia and in collaboration with General Practitioners, Rheumatologists and Orthopaedic Surgeons[13]. Subjects aged over 40 years who fulfilled American College of Rheumatology (ACR) clinical and radiographic criteria for knee OA[14] were examined in this study. Subjects were excluded if any other form of arthritis was present, if there was any contraindication to MRI or if a total knee replacement was planned. The study was approved by the ethics committees of the Alfred and Caulfield hospitals in Melbourne, Australia. All patients gave informed consent.

DATA COLLECTION

At baseline, weight was measured to the nearest 0.1 kg (shoes, socks and bulky clothing removed) using a single pair of electronic scales and height was measured to the nearest 0.1 cm (shoes and socks removed) using a stadiometer. Body mass index (BMI) was calculated as weight/height^2 (kg/m^2).

At baseline, radiographs were taken to determine inclusion in the study. Each subject had a weight-bearing antero-posterior tibiofemoral radiograph, taken in full extension and a skyline (infero-superior) view, taken in the supine position, with 45° of knee flexion (using a perspex positioning wedge). Radiographs were taken of the symptomatic knee. Where both knees had OA and were symptomatic, the knee with least severe radiographic OA was used to reduce subject loss to follow-up for joint replacement surgery. Radiographs were scored independently by two trained observers using a published atlas to classify disease. The radiological features of OA were graded in each compartment (medial tibiofemoral, lateral tibiofemoral and patellofemoral), on a four-point scale (0–3) for individual features of osteophytes and joint space narrowing[15]. In the case of disagreement between observers, the films were reviewed with a third independent observer. Intraobserver reproducibility for agreement on features of OA was 0.93 for osteophytes (grade 0,1 vs 2,3) and 0.93 for joint space narrowing (grade 0,1 vs 2,3). Interobserver reproducibility was 0.86 for osteophytes and 0.85 for joint space narrowing (κ statistic)[16].

RADIOGRAPHY AND FEMORAL SULCUS ANGLE DETERMINATION

Radiographic skyline (infero-superior) views were taken with each subject positioned in supine with 45° of knee flexion (using a perspex positioning wedge). Femoral sulcus angles were measured from these images. The femoral sulcus angle was measured independently by two trained observers as previously described[17,18]. The femoral sulcus angle was defined by lines joining the highest points of the medial and lateral condyles and the lowest point of the intercondylar sulcus (Fig. 1). The angle was measured using the software program Osiris (University of Geneva, Switzerland). All angles were reported in degrees. The intraclass correlation coefficient (ICC) between the two sulcus angle measurements was calculated to assess the reliability of the two sulcus angle measurements using Stata software version 9 (StataCorp 2005). The ICC was estimated to be 0.98 (95% CI 0.97–0.99).

MRI

Each subject had an MRI performed at baseline and approximately 2 years later on the same knee was X-rayed at baseline. Knees were imaged in a sagittal plane on the same 1.5-T whole-body magnetic resonance unit (Signa Advantage HiSpeed GE Medical Systems, Milwaukee, WI, USA) using a commercial receive-only extremity coil. The following sequence and parameters were used: a T1-weighted, fat-suppressed 3D gradient recall acquisition in the steady state; flip angle 55°; repetition time 58 ms; echo time 12 ms; field of view 16 cm; 60 partitions; 512 (frequency direction, superior–inferior) × 512 (phase encoding direction, anterior–posterior) matrix; one acquisition,

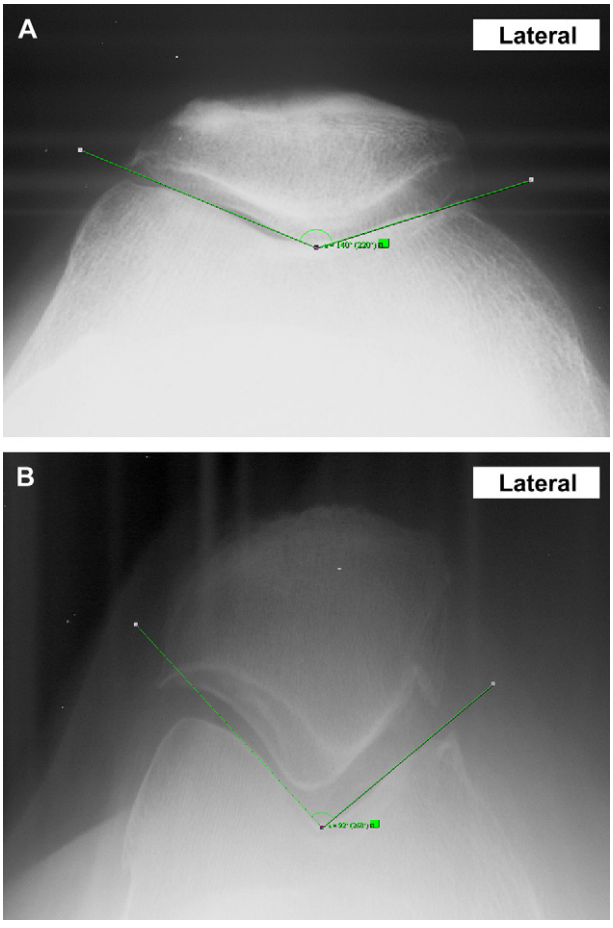

Fig. 1. Skyline radiographs used to measure femoral sulcus angle. The femoral sulcus angle was defined by lines joining the highest points of the medial and lateral condyles and the lowest point of the intercondylar sulcus as previously described[17,18]. (A) Shows a shallow and (B) a narrow sulcus angle.

time 11 min 56 s. Sagittal images were obtained at a partition thickness of 1.5 mm and an in-plane resolution of 0.31 × 0.31 mm (512 × 512 pixels)[9,16].

Patella cartilage volume was determined at baseline and approximately 2 years later by means of image processing in an independent workstation using the software program Osiris (University of Geneva, Switzerland) by creating an isotropic volume from the input images, which were reformatted in the axial plane (voxel dimensions 0.427 × 0.427 × 1.281 mm^3) using a validated method[16,19]. Briefly, we used the patella ridge to divide the patella cartilage into medial and lateral facets. Medial and lateral patella facet cartilage volumes were then measured separately by two trained observers on each MRI by manually drawing disarticulation contours around the cartilage boundaries on each section blind of patient's identification and study sequences as previously described[20] (Fig. 2). The coefficient of variation (CV) for cartilage volume measures was 2.6% for patellar cartilage.

STATISTICAL ANALYSES

Change in knee cartilage volume was obtained by subtracting cartilage volume at follow-up from that at baseline. The annual change was calculated by dividing this figure by the time between MRI scans. The annual change in cartilage volume followed a normal distribution and therefore the association between femoral sulcus angle and change in cartilage volume was explored using multiple linear regression. The contribution of each of the variables to the models was determined by examining the total and partial variance of each of the variables on the patella cartilage volume[21]. A *P*-value of less than 0.05 (two-tailed) was regarded as statistically significant. All analyses were performed using the SPSS statistical package (standard version 15.0, SPSS, Chicago, IL, USA).

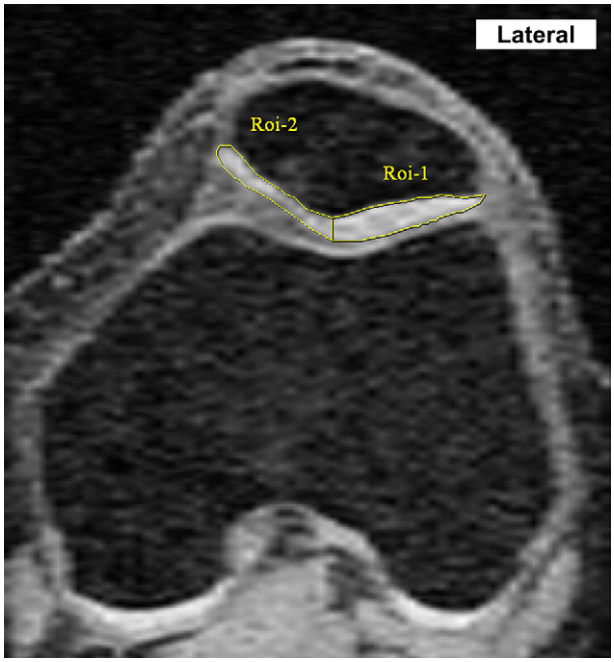

Fig. 2. Patella cartilage volume was determined by means of image processing using the software program Osiris (University of Geneva, Switzerland). The patella ridge was used to divide the patella cartilage into medial and lateral facets. Medial and lateral patella facet cartilage volumes were then measured separately on each MRI by manually drawing disarticulation contours around the cartilage boundaries on each section.

Results

Femoral sulcus angle and patella facet measurements were available for 100 participants. The characteristics of the study population are presented in Table I. The mean (standard deviation (SD)) femoral sulcus angle was 131.8° (10.2°). There was no significant difference in the femoral sulcus angle between men and women ($P = 0.9$). Within the patellofemoral compartment grade 2 or more patellofemoral osteophytes were present in 35% and grade 2 or more patellofemoral joint space narrowing was observed in 12% of participants. Within the medial tibiofemoral compartment, 20% of participants had grade 2 or greater tibiofemoral osteophytes and 27% had grade 2 or greater tibiofemoral joint space narrowing. Within the lateral tibiofemoral compartment, 31% of participants had grade 2 or greater tibiofemoral osteophytes and 11% had grade 2 or greater tibiofemoral joint space narrowing.

In cross-sectional analyses, for every 1° increase in the femoral sulcus angle (i.e., as the femoral sulcus became more shallow), there was a 9.1 mm^3 (95% CI 3.1, 15.0) increase in the medial ($P = 0.003$) and a 15.4 mm^3 (95% CI 1.8, 29) increase in total patella cartilage ($P = 0.03$) volume after adjustment for potential confounders (age, gender, BMI and patella bone volume). A similar trend between femoral sulcus angle and the lateral patella cartilage volume at baseline was also observed ($P = 0.09$). No significant relationship between femoral sulcus angle and annual

Table I
Characteristics of study population

Subject characteristics	Total eligible ($n = 100$)
Age (years)	63.3 (10.2)
Gender (% female)*	61 (61%)
Height (cm)	166.7 (8.9)
Weight (kg)	81 (15.4)
BMI (kg/m^2)	29 (4.9)
Femoral sulcus angle (°)	131.8 (10.2)
Patellofemoral osteophytes ≥grade 2*	35 (35%)
Patellofemoral joint space narrowing ≥grade 2*	12 (12%)
Tibiofemoral osteophytes ≥grade 2*	
Medial compartment	20 (20%)
Lateral compartment	27 (27%)
Tibiofemoral joint space narrowing ≥grade 2*	
Medial compartment	31 (31%)
Lateral compartment	11 (11%)
Patella bone volume (mm^3)	21,064 (4840)
Patella cartilage volume at baseline (mm^3)	
Total	2535 (968)
Medial compartment	972 (408)
Lateral compartment	1563 (592)
Patella cartilage volume at 2 years (mm^3)	
Total	2085 (848)
Medial compartment	779 (371)
Lateral compartment	1313 (539)
Annual change in patella cartilage volume (mm^3)	
Total	231 (236)
Medial compartment	102 (103)
Lateral compartment	128 (148)

All variables described as mean (±SD) unless otherwise stated.
*Described as total number (percentage).

change in cartilage volume over the study period was observed (Table II).

Discussion

The cross-sectional component of this study demonstrated that for every 1° increase in the femoral sulcus angle (i.e., as the sulcus became more shallow), there was an associated 9.1 mm^3 increase in medial patella cartilage volume among people with knee OA. A similar trend was also seen between the femoral sulcus angle and the lateral patella cartilage volume. There was no significant relationship between the femoral sulcus angle at baseline and longitudinal change in patella cartilage volume over 2 years.

No previous study has examined the relationship between the femoral sulcus angle and patella cartilage volume. The femoral sulcus has previously been examined in the context of patellofemoral subluxation/dislocation[17,22,23], trochlear dysplasia[24] and patellofemoral pain syndrome[18]. In a small study that examined 21 women with recurrent patellar dislocation, it was shown that the mean femoral sulcus angle was significantly larger (shallower) in people with recurrent dislocation compared to a control group with no history or signs of dislocation[23]. Another small study of 16 patients with femoral trochlear dysplasia showed that the femoral trochlear groove was significantly shallower compared to 23 people without trochlear dysplasia[24]. In a study comparing 23 women with patellofemoral pain to 12 control subjects, although the femoral sulcus angle was not significantly different between the two groups, a more shallow sulcus was associated with increased lateral patella displacement and tilt[18], which are both thought to contribute towards the pathogenesis of patellofemoral pain.

Although the existing literature has generally supported the notion that a shallower femoral sulcus is associated with decreased patellofemoral congruency and stability[2,5], our study is the first to have examined the femoral sulcus angle in the context of knee OA. Whereas our cross-sectional results demonstrate that a greater medial patella cartilage volume is associated with a shallower femoral sulcus in people with knee OA, the femoral sulcus angle was not a significant determinant of the annual patella cartilage loss. Further studies are required to determine factors influencing the rate of loss of patella cartilage volume. Mechanistically, it may be that a shallower femoral sulcus increases the surface area for articulation with the patella. Increased articular contact area theoretically may reduce contact pressure and thus allow better distribution of retropatellar joint load[25]. Therefore, a shallower rather than a deeper femoral sulcus may be better suited to providing optimal mechanical stimulation to articular cartilage and reducing contact stresses. Moreover, the tendency for the association between the femoral sulcus angle and patella cartilage volume to be significant in the medial patellofemoral compartment may signify that a shallower sulcus may be a determinant that protects the medial compartment from degenerative processes.

The results of this study are limited to people with knee OA and cannot be generalised to non-osteoarthritic populations. Although we demonstrated a cross-sectional association between the femoral sulcus angle and patella cartilage volume, the baseline angle was not significantly associated with change in cartilage volume over 2 years. It may be that our sample size or follow-up period was too small to detect change in cartilage volume that is attributed to the sulcus angle. In cross-sectional analyses, the sulcus angle explained only 8% of the 53% variance in patella cartilage after multiple regression analyses. Although significant, this relatively small contribution towards patella cartilage volume variability may infer that longer time frames are needed to detect significant changes in cartilage volume that are related to the femoral sulcus angle. Another limitation of our study is that the two-dimensional analysis of the femoral sulcus angle employed is highly dependent on the degree of knee flexion, however, a method for accurately measuring the sulcus angle (bony or cartilaginous) from MR images is yet to be validated. Patella tilting and lateralisation were also not measured in this study and may contribute to changes in the patella cartilage.

In conclusion, this study demonstrated that among people with knee OA, a more shallow sulcus is associated with increased medial patella cartilage volume compared to a deeper sulcus angle. Despite this cross-sectional association, the femoral sulcus angle at baseline was not associated with longitudinal change in patella cartilage volume over 2 years. These data suggest that a shallower sulcus in the context of established OA may be an advantageous anatomical variant. Further longitudinal studies are required to elucidate the role the femoral sulcus angle plays in OA.

Table II
The relationship between femoral sulcus angle and patella cartilage volume

	Univariate analysis		Multivariate analysis	
	Regression coefficient (95% CI)*	*P*-value	Regression coefficient (95% CI)	*P*-value
Baseline cartilage volume				
Total patella cartilage	14.6 (−5.4, 35)	0.15	15.4 (1.8, 29)	**0.03**
Medial patella cartilage	8.1 (−0.002, 16.14)	**0.05**	9.1 (3.1, 15)†	**0.003**
Lateral patella cartilage	6.4 (−5.5, 18.4)	0.3	7.2 (−1.2, 15.5)†	0.09
Annual change in cartilage volume				
Total patella cartilage	2.2 (−2.8, 7.2)	0.4	−0.6 (−5.2, 4)	0.8
Medial patella cartilage	0.81 (−1.4, 2.9)	0.46	−0.16 (−2.3, 1.9)‡	0.9
Lateral patella cartilage	1.4 (−1.7, 4.5)	0.4	−0.3 (−3.1, 2.5)‡	0.84

The bold values signify that the findings were statistically significant.

*Change in dependent variable per unit increase in sulcus angle.

†Change in patella cartilage volume (mm^3) per unit increase in sulcus angle in the regression equations after adjustment for age, gender, BMI and a patella bone volume (mm^3).

‡Annual change in patella cartilage volume (mm^3) per unit increase in sulcus angle without and with adjustment for age, gender, BMI, patella bone volume and baseline cartilage volume.

Acknowledgements

We would like to acknowledge Fahad Hanna for technical support with measurement, the MRI Unit at the Alfred Hospital, for their cooperation and Kevin Morris for technical support. We would especially like to thank the study participants who made this study possible.

References

1. Hohe J, Ateshian G, Reiser M, Englmeier KH, Eckstein F. Surface size, curvature analysis, and assessment of knee joint incongruity with MRI *in vivo*. Magn Reson Med 2002;47(3):554–61.
2. Davies AP, Costa ML, Donnell ST, Glasgow MM, Shepstone L. The sulcus angle and malalignment of the extensor mechanism of the knee. J Bone Joint Surg 2000;82-B:1162–6.
3. Elias DA, White LM. Imaging of patellofemoral disorders. Clin Radiol 2004;59(7):543–57.
4. Ledingham J, Regan M, Jones A, Doherty M. Radiographic patterns of osteoarthritis of the knee in patients referred to hospital. Ann Rheum Dis 1993;52: 520–6.
5. Nietosvarra Y. The femoral sulcus in children. J Bone Joint Surg 1994;76-B:807–9.
6. Lanyon P, Jones A, Doherty M. Assessing progression of patellofemoral osteoarthritis: a comparison between two radiographic methods. Ann Rheum Dis 1996; 55(12):875–9.
7. Cicuttini FM, Baker J, Hart DJ, Spector TD. Choosing the best method for radiological assessment of patellofemoral osteoarthritis. Ann Rheum Dis 1996;55(2).
8. Cicuttini FM, Wluka AE, Hankin J, Stuckey S. Comparison of patella cartilage volume and radiography in the assessment of longitudinal joint change at the patellofemoral joint. J Rheumatol 2004;31(7):1369–72.
9. Cicuttini FM, Forbes A, Morris K, Darling S, Bailey M, Stuckey SL. Gender differences in knee cartilage volume as measured by magnetic resonance imaging. Osteoarthritis Cartilage 1999;7:265–71.
10. Eckstein F, Schnier M, Haubner M, Priebsch J, Glaser C, Englmeier KH, *et al*. Accuracy of cartilage volume and thickness measurements with magnetic resonance imaging. Clin Orthop Relat Res 1998;352:137–48.
11. Peterfly CG, van Dijke CF, Janzen DL, Gluer CC, Namba R, Majumdar S, *et al*. Quantification of articular cartilage in the knee with pulsed saturation transfer subtraction and fat-suppressed MR imaging: optimisation and validation. Radiology 1994;192:485–91.
12. Hinterwimmer S, von Eisenhart-Rothe R, Siebert M, Welsch F, Vogl T, Graichen H. Patella kinematics and patello-femoral contact areas in patients with genu varum and mild osteoarthritis. Clin Biomech (Bristol, Avon) 2004;19:704–10.
13. Wluka A, Stuckey S, Snaddon J, Cicuttini F. The determinants of change in tibial cartilage volume in osteoarthritic knees. Arthritis Rheum 2002;46(8): 2065–72.
14. Altman R, Asch E, Bloch D, Bole G, Borenstein D, Brandt K, *et al*. Development of criteria for the classification and reporting of osteoarthritis. Classification of osteoarthritis of the knee. Diagnostic and Therapeutic Criteria Committee of the American Rheumatism Association. Arthritis Rheum 1986;29(8):1039–49.
15. Burnett S, Hart DJ, Cooper C, Spector TD. A Radiographic Atlas of Osteoarthritis. London: Springer-Verlag 1994.
16. Wluka AE, Davis SR, Bailey M, Stuckey SL, Cicuttini FM. Users of oestrogen replacement therapy have more knee cartilage than non-users. Ann Rheum Dis 2001; 60(4):332–6.
17. Brattstrom H. Shape of the intercondylar groove normally and in recurrent dislocation of the patella. Acta Orthop Scand 1964;68:85–138.
18. Powers CM. Patellar kinematics, Part II: The influence of the depth of the trochlear groove in subjects with and without patellofemoral pain. Phys Ther 2000;80(10): 965–73.
19. Wluka AE, Forbes A, Wang Y, Hanna F, Jones G, Cicuttini FM. Knee cartilage loss in symptomatic knee osteoarthritis over 4.5 years. Arthritis Res Ther 2006; 8(R90).
20. Cicuttini FM, Wluka AE, Hankin J, Wang Y. Longitudinal study of the relationship between knee angle and tibiofemoral cartilage volume in subjects with knee osteoarthritis. Rheumatology 2004;43:321–4.
21. Rosner B. Fundementals of Biostatistics. 5th edn. California: Duxbury Thomson Learning 2000.
22. McNally EG, Ostlere SJ, Pal C, Phillips A, Reid H, Dodd C. Assessment of patella maltracking using combined static and dynamic MRI. Eur Radiol 2000; 10:1051–5.
23. Kujala UM, Osterman K, Kormano M, Melimarkka O, Hurme M, Taimela S. Patellofemoral relationships in recurrent patella dislocation. J Bone Joint Surg 1989;71-B:788–92.
24. Pfirrmann CWA, Zanetti M, Romero J, Hodler J. Femoral trochlear dysplasia: MR findings. Radiology 2000; 216:858–64.
25. Moro-oka T, Matsuda S, Miura H, Nagamine R, Urabe K, Kawano T, *et al*. Patellar tracking and patellofemoral geometry in deep knee flexion. Clin Orthop Relat Res 2002;394:161–8.