Anatomy and surface geometry of the patellofemoral joint in the axial plane

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We studied the anatomy of the patellofemoral joint in the axial plane on cryosections from a cadaver knee and on MR arthrotomograms from 30 patients. The cryosections revealed differences in the geometry and anatomy of the surface of the articular cartilage and corresponding subchondral osseous contours of the patellofemoral joint. On the MR arthrotomograms the surface geometry of the cartilage matched the osseous contour of the patella in only four of the 30 knees. The articular cartilaginous surface of the intercondylar sulcus and corresponding osseous contour of the femoral trochlea matched in only seven knees.

Since MR arthrotomography can distinguish between the surface geometry of the articular cartilage and subchondral osseous anatomy of the patellofemoral joint, it allows the surgeon and the radiologist to appraise the true articulating surfaces. We therefore recommend MR arthrotomography as the imaging technique of choice.

J Bone Joint Surg [Br] 1999;81-B:452-8.

Received 22 January 1998; Accepted after revision 14 August 1998

Many clinical investigators have related the radiological appearances of the patellofemoral joint to patellofemoral pain,^{1,2} malalignment of the patellofemoral joint,³⁻⁶ chondromalacia of the patella,⁵ abnormal patellofemoral angulation,⁷ congruence,^{1,8,9} patellar subluxation,¹⁰⁻¹² patellar dislocation,¹³⁻¹⁵ dysplasia of the patella¹⁶ and of the femoral trochlea,^{8,15} patellar position,^{17,18} and movement.¹⁹

Studies of the anatomy and geometry of the articular cartilage in the human patellofemoral joint, based on analyses of surface curvature, have found variations in the ridges of the articular surface of the patella and the femoral trochlea.²⁰

We have compared the bony anatomy of the patellofemoral joint in the axial plane with the surface geometry of the corresponding articular cartilage on cryosections and arthrotomograms. On the cryosections, we studied the surface of the articular cartilage and corresponding subchondral osseous contours of the patellofemoral joint at various levels. On MR arthrotomograms obtained with the knee in extension, we studied the relationship of the median cartilage ridge to the osseous prominences on the patella. We compared the deepest part of the cartilage concavity of the intercondylar sulcus of the femur to the corresponding concavity of the osseous contours on the trochlea.

Our two null hypotheses were based on existing published literature^{1-11,13-19} on the radiological appearance of the patellofemoral joint in the axial plane, since there is a match between the median articular cartilage ridge and the corresponding osseous prominence of the patella and between the concavity of the cartilage surface of the intercondylar sulcus and the concave osseous contour of the femoral trochlea.

We formulated a third hypothesis that, in the contact zone, opposing articular cartilage surfaces of the patellofemoral joint match, but corresponding subchondral osseous contours in a given patellofemoral joint in the axial plane do not necessarily do so.

Patients and Methods

Cryosectional anatomy. One fresh cadaver knee from a 36-year-old woman was procured through the Willed Body Donation Program, Department of Biological Structure, University of Washington School of Medicine, Seattle. After resolution of rigor mortis, the femoral artery was injected with red contrast medium and the joint cavity with blue-tinted saline to unfold and demarcate the synovial lining. To maintain the extended position and to avoid undue soft-tissue deformation, a plaster cast was applied to the knee before it was frozen at -20°C. The frozen knee was examined by CT and freeze-embedded in carboxymethyl-

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0301-620X/99/38758 \$2.00

cellulose gel, before being stabilised in a block of ice. The specimen was serially sectioned in the axial plane on a heavy-duty sledge cryomicrotome (PMV 450 MP, Stockholm, Sweden).²¹ After carefully trimming sections of 5 to 10 μm off the frozen block, the sectioning cycle was interrupted at submillimetre cutting intervals. The surface of the specimen was cleaned and slightly thawed with compressed air and then coated with an ultrathin film of ethylene glycol to prevent recrystallisation. Overview and high-power close-up photographs were taken of the surface on high-resolution colour transparency film using a customised 35 mm camera, electronic flash and a flat-field macro lens.²¹

MR arthrotomography. A series of 30 consecutive patients, 12 women with a mean age of 42 years (22 to 72) and 18 men with a mean age of 38 years (19 to 61), referred to our clinic for knee disorders related to knee instability or meniscal damage, gave their informed consent to enter the gadolinium-enhanced MR arthrotomography study. We excluded patients with anterior knee pain resulting from injury, chronic arthritic conditions, or patellar dislocation as revealed by standard radiographs.

MR arthrotomograms were obtained from all patients according to protocol. Gadolinium-enhanced MR arthrotomography was carried out using a 1.5 imaging system (Magnetom Vision; Siemens Erlangen, Germany) with a superficial knee coil. After intra-articular injection of a solution of 0.1 ml gadopentate dimeglumine and 15 to 20 ml of physiological saline (0.9% NaCl), the following sequences were applied: 1) T1-weighted sagittal sequence (TR 720, TE 15); 2) T2-weighted double-echo coronal sequence (TR 2200, TE 20/90); and 3) two gradient-echo sagittal and axial sequences (Flash 2D). The slice thickness was 3 mm except for the T2-weighted sequence in which the thickness was 4 mm. During imaging, the subject lay supine with the quadriceps muscle relaxed and the knee extended. In the extended knee position, axial views of the patellofemoral joint were obtained at 3 mm intervals. We selected axial views of the patella at midpatellar height, and of the femoral trochlea at its deepest concavity.

Measurement technique. We studied the axial views of 20 left and 10 right knees. On each MR arthrotomogram, we measured the distance from a medial tangent to the median cartilage ridge and to the osseous prominence of the patella, and the distance from a medial tangent to the deepest part of the concavity of the surface of the articular cartilage of the intercondylar sulcus and to the deepest part of the concavity of the osseous contour of the femoral trochlea. We used standard measurement lines, some of which have been used to analyse the subchondral osseous contours by conventional radiography, axial CT and MRI.^{1,3-6,13,14,17,18}

Patellar cartilage and osseous measurements (Fig. 1). The baseline **bl** was drawn on the axial view of the patella at the widest part of the subchondral osseous contour. A tangent **m** was constructed to the most medial subchondral osseous contour of the patella, perpendicular to the base-

Fig. 1

Diagram of the measurement technique on MR arthrotomograms for the axial plane of the right knee; (P, patella; F, femur).

line. A tangent running parallel to the baseline and intersecting with the cartilage surface of the median ridge of the patella was identified as **c** and another parallel tangent intersecting with the subchondral osseous prominence as **s**. Lines parallel to the medial tangent were drawn perpendicular from the baseline to **c** and to **s**. Lines drawn perpendicular to the medial tangent (parallel to the baseline) were designated **mc** and **ms** (Fig. 1). The lengths of the lines **mc** and **ms** were measured in millimetres with a micrometer.

Trochlear cartilage and osseous measurements. The baseline **BL** was constructed tangential to the most posterior subchondral osseous contours of the posterior aspect of the medial and lateral femoral condyles (posterior femoral tangent, PFT). A tangent **M** was then constructed at the most medial osseous border of the medial femoral condyle perpendicular to **BL** (Fig. 1). At the deepest part of the surface concavity of the articular cartilage of the intercondylar sulcus of the femur, we designated a point **C**, and at the deepest point of the osseous concavity, a point **S**. Two lines parallel to the baseline and perpendicular to the medial tangent of the femoral trochlea were constructed and measured (**MC** and **MS**).

Statistical analysis. Based on the indexed literature,^{1-11,13-19} the null hypotheses were that **mc** = **ms** and **MC** = **MS**. For analysis of data we used the following statistical software: SAS (SAS Institute, Cary, North Carolina), SPSS (SPSS Inc), and StatXact (Cytel Software Corporation, Cambridge, Massachusetts). We used paired sample statistics to measure the differences of **mc** to **ms** and **MC** to **MS** to find the critical *t*-statistics and the associated *p* values. A *p* value <0.05 was considered significant. We used the Wilcoxon signed-rank test for differences in the median **mc** minus **ms** and **MC** minus **MS**, calculated the 95% confidence interval (CI) for Hodges-

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2d

Fig. 2e

Fig. 2f

Fig. 2g

Fig. 2h

Figure 2. Cryosections of the patellofemoral joint, right knee in extension, axial plane, cryoplaning sequence proximal to distal. Figure 2a – On this axial section through the proximal part of the joint, the articular cartilage surface of the median ridge and the subchondral osseous prominence of the patella match. The asymmetry of cartilage cover of the intercondylar sulcus is evident. The asymmetrical superior articular cartilage covering of the lateral part of the femoral trochlea is in opposition to the lateral facet of the patella; the median ridge of the patella is opposite the supratrochlear fat pad. The medial and lateral parapatellar plicae are evident. The potential contact zone of the patellofemoral cartilage is located on the lateral part of the intercondylar sulcus of the femoral trochlea. Figure 2b – Asymmetrical cartilage cover of the femoral trochlea. The patellofemoral contact zone is restrained to the lateral part of the intercondylar sulcus. Figure 2c – The median ridge of the patella is in contact with the proximal part of the intercondylar sulcus. The location of the contact zone is lateral to central. Figure 2d – The median ridge of the patella and the osseous prominence do not match. The proximal part of the intercondylar sulcus is covered by a thin layer of cartilage (proximal medial part of the femoral trochlea). There is a gradual lateral-to-central shift of the contact zone. Figure 2e – Asymmetrical medial ridge with respect to the osseous prominence of the patella. The deepest part of the intercondylar cartilage sulcus is medial to the deepest part of the femoral trochlea. The articular cartilage surfaces are in perfect opposition; osseous contours do not match. There is gradual shifting of the contact zone lateral to central to medial. Figure 2f – Asymmetrical cartilage cover of the patella; the thickness of the medial facet is increasing. The intercondylar cartilage sulcus and the femoral trochlea are in matching contours. The patellofemoral osseous contours do not match. The articular cartilage surfaces are congruent. There is a central-to-medial shift in the contact zone of the articular cartilage. Figure 2g – Asymmetry between the cartilage ridge and the osseous prominence of the patella. The intercondylar cartilage sulcus and the osseous part of femoral trochlea have a symmetrical shape. The patellofemoral contact area is asymmetrical medially. There is a medial patellofemoral contact zone. Figure 2h – Note the asymmetry between the cartilage ridge and osseous contour of the patella. The intercondylar cartilage sulcus and the osseous contour of the femoral trochlea match. The patellofemoral contact zone is located medially.

Lehmann estimates of median differences, and applied Student's *t*-test for mean values and the sign test for location.

Results

Cryosectional anatomy. Axial sections of the patellofemoral joint are represented in Figure 2. Axial views of the geometry of the patellofemoral joint surface and corresponding osseous contours are shown in Figures 2a to 2h. **MR arthrotomography.** Axial images of MR arthrotomo-

graphic slices of an individual patellofemoral joint from superior to inferior are shown in Figures 3a to 3i. There is considerable lateral-to-medial and superior-to-inferior variation in the retropatellar thickness of the articular cartilage.

For the patellar cartilage and osseous contour, the mean distance between the ridge of the median articular cartilage and the medial tangent (**mc**) was 20.3 ± 3.0 mm (12.3 to 27.6). The mean distance between the medial tangent and subchondral osseous prominence of the patella (**ms**) was 18.9 ± 3.2 mm (13.2 to 24.6).

Fig. 3a

Fig. 3b

Fig. 3c

Fig. 3d

Fig. 3e

Fig. 3f

Fig. 3g

Fig. 3h

Fig. 3i

Figure 3. MR arthrotomograms of the patellofemoral joint with the right knee in extension; axial plane. Photographs of arthrotomographic slices from a single knee of a 35-year-old man. Figure 3a – The medial ridge of the patella resting on the supratrochlear fat pad. Figures 3b to 3g – Progressive mismatch of the contour of the cartilage surface of the medial facet and the subchondral osseous contour of the patella with gradual shift of the contact zones from lateral to central (c, d and e) and central-to-medial contact zones (f and g). Figures 3h and 3i – The medial contact zone. There is complete mismatch of the surfaces of the articular cartilage and corresponding subchondral osseous contours, and a medial shape of the contact zone.

In 19 knees the position (**mc**) of the ridge of the articular cartilage of the patella was lateral to the corresponding subchondral osseous prominence (**ms**). In seven knees, **mc** was medial to **ms** and in four **mc** and **ms** were coincident measured from the medial tangent (Fig. 4).

For the concavities of the deepest part of the surface of the articular cartilage of the intercondylar sulcus and the corresponding deepest point of the femoral trochlea, the mean **MC** was 43.6 ± 6.7 mm (28.3 to 65.5). The mean distance between the deepest point of the subchondral osseous concavity of the femoral trochlea and the medial tangent (**MS**) was 44.9 ± 6.0 mm (35.4 to 65.5).

In 19 knees the distance **MC** was greater than the distance **MS**, in four the distance **MC** was shorter than **MS**, and in seven **MC** and **MS** were equal (Fig. 5).

Statistical analysis. The mean measurements of **mc** and

ms and **MC** and **MS** are given in Table I and the mean differences of **mc** minus **ms** and **MC** minus **MS** are given in Table II. Table III gives the frequencies, ranks, and test statistics of **ms** minus **mc** and **MS** minus **MC**. The level of significance was at $p < 0.05$.

Discussion

Our study supports the theory that there is a difference in the surface geometry of the articular cartilage and the corresponding subchondral osseous anatomy of the patella and of the femoral trochlea (Fig. 6). On cryosections and on MR arthrotomograms, the shape and geometry of the surface of the articular cartilage and corresponding osseous morphology vary according to the level of the axial plane. There is also considerable intraspecimen and interspecimen variation.

Fig. 4

Diagram showing the differences in contour between the median cartilage ridge of the patella and the corresponding osseous prominence of the subchondral bone.

Table I. The distance (mm) of **mc** and **ms** (patella) and **MC** and **MS** (femoral trochlea) for the 30 patients (see Fig. 1)

	Patella		Femoral trochlea	
	mc	ms	MC	MS
Mean distance	20.11	18.85	43.32	44.71
SEM	0.5516	0.5603	1.0011	0.8901
SD	3.02	3.06	5.48	4.87
Minimum distance	12	13	28	35
Maximum distance	25	25	55	57

Table II. Mean differences (mm) of **mc** minus **ms** and **MC** minus **MS** for the 30 patients (see Figs 4 and 5)

	Patella mc minus ms	Femoral trochlea MC minus MS
Mean difference	1.25	-1.38
SEM	0.5966	0.5121
SD	3.26	2.8
Minimum differences	-7.75	-7.02
Maximum difference	6.53	5.43

Fig. 5

Diagram showing the differences in the deepest part of the articular cartilage surface of the intercondylar sulcus and the corresponding deepest point of the femoral trochlea.

Table III. Frequencies *, ‡ and ranks †§, of **ms** and **mc**, **MS** and **MC** for the 30 patients

	Differences and ranks			
	Negative	Positive	Ties	p value
Patella				
ms - mc	19	7	4	0.031* 0.040†
Femoral trochlea				
MS - MC	4	19	7	0.003‡ 0.037

* sign test (two-tailed, binominal distribution used)

† Wilcoxon signed-rank test (based on positive ranks)

‡ sign test (two-tailed)

§ Wilcoxon signed-rank test (based on negative ranks)

Fig. 6a

Fig. 6b

Diagrams of the differences in the surface geometry of the articular cartilage and corresponding osseous anatomy in the axial plane with the right knee in extension.

Fig. 7a

Fig. 7b

Fig. 7c

Fig. 7d

Imaging modalities and diagrams of same right knee in extension, axial plane. Note the error in the radiological appearance of the osseous contours (a and c) and the perfect matching of articular cartilage surfaces in the axial plane of the same right knee on double-contrast MR arthrotomography (b and d).

Table III gives the analysis of the frequency distribution of the mean differences to the medial measurement tangents. In the axial plane, the mean distances between the medial tangent and the osseous prominence and the medial tangent and the median cartilage ridges of the patella were the same in four knees. In the axial plane, the deepest part of the concavity of the articular surface of the intercondylar sulcus corresponded to the deepest part of the concavity of the osseous contour of the femoral trochlea on seven arthrotomograms.

Despite the fact that the median cartilage ridges of the patellae match the corresponding osseous prominences on four arthrotomograms, there is a considerable discrepancy and morphological variation in other patellae. The null hypotheses, outlined in the introduction, that the surface of the articular cartilage and the corresponding anatomy of the osseous contour match, are refuted by our observations of the patellae and the femoral trochleae in our study.

Radiological patellofemoral indices^{1,4,6,7,13-16,22} allow description of the osseous contours of the patellofemoral articulation according to conventional radiography and CT. These modalities and indices do not give the specific relationships of the geometry of the surface of the articular cartilage to the subchondral osseous anatomy of the patella or femoral trochlea in the individual patient.

MR arthrotomography is a technique which does not expose the patient to radiation unlike others such as radiography, CT or scintigraphy.²³ It does, however, require an intra-articular injection of a contrast medium and exposes the patient to a magnetic field. The procedure is relatively costly, but provides information not revealed by other methods.

Figure 7 illustrates the information revealed in plain radiographs and double-contrast MR arthrotomography. Our study of the cryosections, reinforced by the evidence from the arthrotomograms, contradicts the concepts stated in the null hypotheses for most patellofemoral joints, but our findings support our third hypothesis. Despite the fact that the osseous anatomy of the patellofemoral joint did not match with the corresponding surface geometry of the articular cartilage, individual intraspecimen matching of opposing articular cartilage surfaces in the contact zone was evident on axial cryosections and on MR arthrotomograms in our study.

Before decisions are made concerning the diagnosis and management of patellar dysplasia or dysplasia of the femoral trochlea, imaging modalities reflecting the opposing surface geometry of the articular cartilage should be considered. The intra-articular injection of a contrast medium for double-contrast arthrography, axial CT arthrotomography or at MR arthrotomography may offer the knee surgeon and the radiologist an accurate insight into the functional congruence of opposing articular surfaces. Abnormalities of joint congruence should include a detailed analysis of the complex surface geometry of the articular cartilage of the patellofemoral joint in the axial plane.

Bernhard Carrel, illustrator, Alterswil, Switzerland, coproduced with the first author (H.-U.S.) the schematic drawings. Lottie B. Applewhite, Chapel Hill, North Carolina, served as the author's editor. Enkelejd Hashorva, Institute of Mathematical Statistics and Actuarial Sciences, University of Bern, provided the interpretation of the statistical results.

This work has been supported by grant no. 11-658 from the Swiss National Science Foundation.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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