Patellar motion analyzed by magnetic resonance imaging

Urho M. Kujala[1], Kalevi Österman[2], Martti Kormano[3], Markku Komu[3] and Dietrich Schlenzka[2]

We have analyzed the normal patellar motion during the first 30° of knee flexion by magnetic resonance imaging (MRI). Ten males and 10 females without knee symptoms were examined. The patellar articulation was imaged both sagitally and axially with the knee flexed 0, 10, 20, and 30°. The axial images were produced through the middle of the patellar articular cartilage. When the knee was in extension compared to 30° flexion, the sulcus angle was greater, the lateral patellofemoral angle was smaller, there was more lateral patellar displacement, the patella tilted more laterally, and the congruence angle was directed more laterally. Differences between males and females were found.

Patellofemoral incongruence has been claimed to predispose to chondromalacia, arthrosis, patellar subluxation, and dislocation (Ficat and Hungerford 1977, Ahlbäck and Mattsson 1978, Schlenzka 1980, Kujala et al. 1986c). Axial plain x-ray evaluation of the patellofemoral incongruence requires knee flexion of at least 25–30°. Computerized tomography has been used to evaluate the patellofemoral motion during the first 30° of knee flexion (Delgado-Martins 1979, Martinez et al. 1983, Sasaki and Yagi 1986, Schutzer et al. 1986a and 1986b). However, the normal position of the patella in knee extension and during the first 30° of knee flexion is not well defined, even though it is supposed that incongruence already below 30° knee flexion may have clinical significance (Sasaki and Yagi 1986).

We have analyzed the normal patellar motion during 0–30° knee of flexion using magnetic resonance imaging (MRI) in young adult males and females.

Subjects and methods

The subjects comprised 10 male (age 29 ± 6 years, mean ± SD) and 10 female (age 25 ± 4 years) volunteers without knee symptoms according to clinical history and examination. Within each group, five right and five left knees were examined.

The MR images were all performed on an Acutscan 0.02 T (Instrumentarium, Palomex division, Finland) using a special surface coil; The imaging volume of this U-shaped coil is 120 x 120 x 150 mm^3. The imaging matrix consists of 128 x 256 (width x height) pixels. The displayed pixel size is 1.15 x 0.78 mm^2, so the

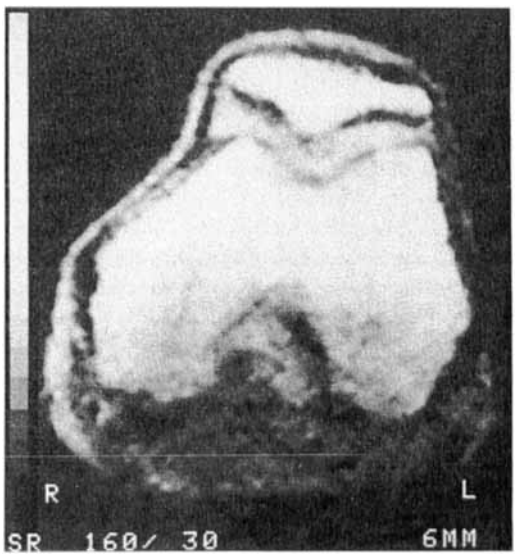

Figure 1. Axial MR image of the patellar joint. The T1-weighted partial saturation sequence SR 160/30 and 6 mm slice thickness were used. The imaging time was 5.5 min.

Sports Medical Research Unit[1], Paavo Nurmi Center, Turku, Orthopedic Hospital of the Invalid Foundation[2], Helsinki, and Department of Diagnostic Radiology[3], University Central Hospital, Turku, Finland

Correspondence: Dr. Urho Kujala, Sports Medical Research Unit, Paavo Nurmi Center, Kiinamyllynkatu 10, SF–20520 Turku, Finland

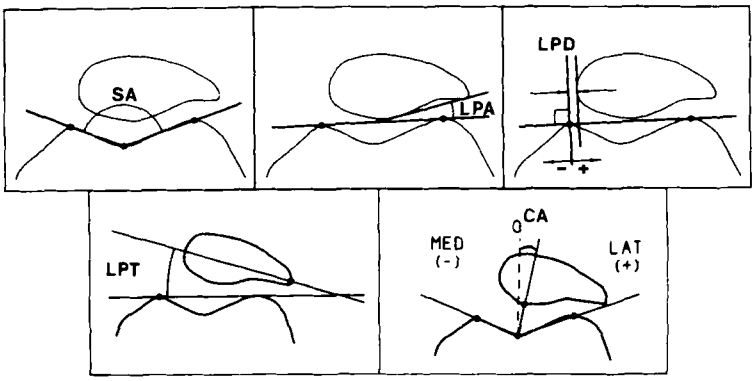

Figure 2. Patellofemoral indices: SA, sulcus angle; LPA, lateral patellofemoral angle; LPD, lateral patellar displacement; LPT, lateral patellar tilt; and CA, congruence angle.

field of the view of the image is 146 x 200 mm^2. The slice thickness was 6 mm. The T1-weighted partial saturation sequence SR 160/30 was used in imaging the knee in axial and sagittal directions. With eight signal averages, the total imaging time was 5.5 min.

During imaging the subject was lying supine. Special equipment was used to support the knee to predetermined flexion angles and to maintain the forefoot in the vertical position. The imaging was done with the quadriceps muscle relaxed and the knee flexed 0, 10, 20 and 30°. In each knee position an axial image was used first to identify the sagittal plane. The second image was a midpatellar sagittal section, and the third image was axial (Figure 1) and focused exactly through the middle of the patellar articular cartilage. When the knee was in extension, an additional axial image was produced during maximal isometric quadriceps muscle contraction.

The following indices, part of which have been used earlier in radiographic studies, were measured using a computer-assisted system from the axial images (Figure 2): sulcus angle (Brattström 1964); lateral patellofemoral angle; and lateral patellar displacement (Laurin et al. 1979); lateral patellar tilt, which is the angle between the line intersecting the widest bony structure of the patella and the line passing the anterior surfaces of the femoral condyles tangentially; and congruence angle (Merchant et al. 1974).

A test phantom was used to analyze the distortion of the distances in the MR images. The highest image nonlinearity within the imaging volume was 2.3 percent and was still smaller in the central parts of the image, where the patellar articulation was focused. In the analysis of the reproducibility of the method, 2 different physicians measured the same series of images of nine healthy and six pathologic knees as a blind test. The correlation coefficients between the measurements made by different physicians were 0.84–0.96 for all the different angles.

The Mann-Whitney *U*-test and *t*-test were used for comparison of the means.

Results

The sulcus angle was 13 ± 13° sharper in 30° of knee flexion than in full extension ($P < 0.001$). This difference was greater in males than in females (Table 1). The lateral patellofemoral angle increased 6 ±5° during the first 30° of knee flexion ($P < 0.001$). Lateral patellar displacement decreased 4 ± 3 mm during the 30° knee flexion ($P < 0.001$). In this respect, there was no sex difference, but the displacement decreased earlier in males than in females (Table 1). Lateral patellar tilt decreased 5 ±4° during the 30° knee flexion ($P < 0.001$), which was greater for males than for females. The congruence angle shifted 31.3 ± 12.8° medially during the 30° of knee flexion ($P < 0.001$). In extension the congruence angle was negative (open medially) for 1 male and for no female. The corresponding numbers were 6/4 (males/females) in 10°, 7/6 in 20°, and 9/9 in 30° of knee flexion. In 30° of knee flexion, the congruence angle was zero for 1 male and 1 female.

During active isometric quadriceps muscle contraction with the knee in extension, there was no difference in the mean values of lateral patellar displacement as compared with the corresponding image without muscle contraction; but lateral patellar tilt decreased 4 ±5° during the quadriceps contraction ($P < 0.01$). Muscle force thus moved the patella medially in half of the subjects and laterally in half of the subjects, whereas lateral patellar tilt increased in only 1 male and 1 female.

Table 1. Numeric values of the indices (mean *SD*) measured from the axial MR images with the knee flexed 0, 10, 20, and 30° and the change of the indices during 0–30° knee flexion

Index	Flexion angle	Males (n 10)		*P*– value[a]	Females (n 10)	
Sulcus	0	159	*4*		155	*4*
angle (°)	10	158	*7*		156	*8*
	20	147	*10*		155	*11*
	30	140	*10*		148	*13*
Change	0–30	−19	*11*	< 0.05	−7	*12*
Lateral	0	0	*5*		4	*5*
patellofemoral	10	4	*7*		4	*4*
angle (°)	20	7	*7*		6	*4*
	30	8	*5*		8	*6*
Change	0–30	8	*5*		4	*4*
Lateral	0	0	*4*		1	*2*
patellar	10	−3	*4*	< 0.05	1	*2*
displacement	20	−4	*3*	< 0.05	−2	*3*
(mm)	30	−4	*2*		−4	*2*
Change	0–30	−4	*4*		−5	*2*
Lateral	0	18	*5*		16	*5*
patellar	10	15	*4*		17	*4*
tilt (°)	20	12	*5*		14	*3*
	30	12	*5*		13	*3*
Change	0–30	−6	*4*	< 0.05	−3	*3*
Congruence	0	21	*13*		15	*12*
angle (°)	10	2	*20*		2	*11*
	20	−10	*10*		−6	*10*
	30	−11	*7*		−15	*9*
Change	0–30	−32	*13*		−31	*14*

[a] *P– values indicate sex difference.*

Discussion

When analyzing different reports on plain radiographic methods for visualizing the patellar articulation, various modifications have been presented with respect to knee position and x-ray-beam angle. This makes interpretations of numeric values from different studies difficult. Because the patella lies in a lateralized and tilted position in knee extension, but is often congruent in 30° of knee flexion, abnormal motion in patients with patellar dislocations and subluxations presumably starts from the beginning of knee flexion. This view is supported because the Q angle decreases when flexing knees 30° (Kujala et al. 1986b), which decreases the risk of dislocation when the knee is flexed.

Our method is technically easy to repeat. The axial image positioning used for the measurements can be determined exactly within 1 mm on the basis of the earlier sagittal image. The axial image was produced through the exact center of the patellar articular cartilage to standardize the method. Probably this projection is the most informative regarding the condylar support for the patella at different angles.

Delgado-Martins (1979) first used computerized tomography to study the position of the patella. The study showed that when the knee is in full extension the patella usually lies more laterally in a tilted position than in 30° of flexion. This finding accords with later studies using computerized tomography (Martinez et al. 1983, Sasaki and Yagi 1986, Schutzer et al. 1986), as well as with our MRI study.

In the earlier studies with computerized tomography, normal values for males and females were not given separately. We think that normal values are needed for each sex. In 20° of knee flexion, all the indices measured from axial images showed that in females the patella lay more laterally in the femoral sulcus, and the femoral condyles gave less support to the patella. However, only lateral patellar displacement was significantly different (Table 1). Such differences may explain why patellofemoral problems are more common in females (Goodfellow et al. 1976, Kujala et al. 1986a).

There is some variation in patellar tilting and lateralization at the beginning of knee flexion. Schutzer et al.

(1986a) categorized their patients with patellofemoral pain into three groups: subluxation without tilt, subluxation with tilt, and tilt without subluxation. This somewhat constrained categorization shows that there are differences in the patellar motion and shows the need for individual analysis to reveal the mechanical fault to be corrected. If we define patellofemoral articulations as congruent when the congruence angle is zero or open medially, we can conclude that all the knees are congruent in 30° of knee flexion, but not at smaller flexion angles. We have analyzed a series of patients with recurrent patellar dislocations, and all the indices that were used also in the present study showed the clearest differences during 0-10° of knee flexion when compared with normal values. Axial plain x-ray evaluation, which requires knee flexion of at least 25–30° seems to miss clinically important information.

Our finding that isometric quadriceps muscle contraction decreases the lateral patellar tilt when the knee is extended, but may move the patella either medially or laterally, agrees with earlier studies made with computerized tomography (Martinez et al. 1983, Sasaki and Yagi 1986).

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