Skeletal Radiol (1997) 26:597–601

ARTICLE

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Malposition of the tibial tubercle during flexion in knees with patellofemoral arthritis

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Abstract *Objective.* To assess the mechanisms contributing to the induction of patellofemoral arthritis (PF-OA).
Design and patients. A computed tomography scan was taken at three levels of the lower extremity in full extension and at 30° of flexion. The cuts were superimposed and 12 parameters were compared in 17 PF-OA knees and 27 normal knees to assess the rotation angle of the tibial tubercle.
Results. Although the tibial tubercle was in almost the same position in full extensioin in the normal and PF-OA knees, it was positioned significantly laterally at 30° of flexion in PF-OA knees. Also the articular surface of the lateral femoral condyle was significantly narrower or steeper in PF-OA knees.
Conclusion. Anatomic variations and mechanical abnormalities were identified in the PF-OA knees.

Key words Patellofemoral arthritis · Computed tomography · Tibial tubercle · Tibial rotation

Introduction

Tibial rotation exerts a major influence on patellar tracking [1, 2]. The position of the tibial tubercle relative to the femoral epicondyles varies with the flexion angle, and this affects patellar tracking. Although computed tomography (CT) is useful for evaluating patellar position relative to the femoral condyles, in previous studies [2–9] CT scans have been taken only at one flexion angle of early knee flexion, and only static analyses have been performed. In the present study the CT scan was taken at two flexion angles, namely full extension and 30° of flexion, to assess the tibial tubercle position relative to the femoral epicondyles. New parameters to evaluate the position of the tibial tubercle were established with the fiducial point as the central point of the femoral epicondyles. By comparing the position of the tibial tubercle in full extension and at 30° of flexion, a mechanical analysis could be done. The anatomic configuration of the femoral condyles was also assessed using three other parameters. A total of 12 parameters were used to assess possible mechanisms contributing to the induction of patellofemoral arthritis (PF-OA).

Materials and methods

Seventeen knees in 16 female patients with PF-OA and 27 normal knees in 27 female volunteers were evaluated. In knees with PF-OA, the joint space between the lateral facet of the patella and the lateral femoral condyle had disappeared on the axial radiograph taken by the Merchant technique. Otherwise, the femorotibial joint space was intact or slightly decreased on a standing anteroposterior radiograph. Knees with minor osteophytes were included in this study. The femorotibial angle was between 175° and 177° in all knees. Knees with valgus deformity were excluded from the study because valgus deformity is thought to be the main factor in inducing PF-OA (Fig. 1). The mean age of the subjects was 68.5 years.

We strictly selected the volunteers for the normal controls because the parameters used in this study were new and normal values were necessary. They were women over 40 years old (mean age 53.4 years) because some younger women tend to complain of knee pain of unknown etiology. They had had no subjective knee complaints,

Fig. 1 Knees with lateral patellofemoral osteoarthritis and without valgus deformity were evaluated

no abnormality was identified on their radiographs, and their knees could be fully extended and fully flexed. It was difficult to find volunteers over 60 years old who met these criteria. The mean age of the volunteers was therefore younger than that of the patients.

The patient was placed supine in the CT scanner, and the lower extremity positioned so that the long axis of the tibia was parallel to the bed in the sagittal and coronal planes; this was confirmed with a scanogram. The procedure was performed both in full extension and at 30° of flexion. In this position the knee will not develop varus or valgus deformity even in knee flexion. In addition, a CT scan was taken perpendicular to the long axis of the tibial shaft. Using this method a consistent CT image can be obtained at any flexion angle between full extension and 90° of flexion [1]. The quadriceps muscle was not contracted in this study. A CT scan was taken at the level of the femoral epicondyles, the tibial tubercle and the ankle in both full extension and 30° of flexion. When the CT scan was taken at the level of the femoral epicondyles, the image sometimes did not clearly reveal the medial epicondyle. If this occurred an additional CT scan was taken after the scan level had been moved 2 mm distally or proximally until the scan clearly revealed the medial epicondyle. The central point of the medial epicondyle was used for the transepicondylar line.

In the supine patient it was difficult to position the leg at more than 30° of flexion in the CT scanner. An image in a plane perpendicular to the long axis of the tibia was used for all measurements (Fig. 2). The cuts were superimposed, and 12 parameters were measured with the fiducial point as the central point of the transepicondylar line (point C). At full extension, the tibial tubercle angle (TT angle), the tibial tubercle–lateral condyle angle (TT-LC angle), and the medial and lateral malleolar line angle (ML angle) were measured. The TT angle was the angle between the transepicondylar line and the line from the central point of the patellar ligament to point C (Fig. 3). The TT-LC angle was the angle between the line from the central point of the patellar ligament to point C and the line from the highest point of the lateral condyle to point C (Fig. 3). These parameters were then used to assess the position of the tibial tubercle relative to the femoral epicondyles. The patellar ligament was used for the measurement because this is located lateral to the tibial tubercle in some knees [6]. The ML angle was the angle between the transepicondylar line and the medial and lateral malleolar line (Fig. 4). This measurement was used to assess the rotation angle of the tibia relative to the transepicondylar line. At 30° of knee flexion, these three parameters were again measured. The difference in the values of each measurement in full extension and at 30° of flexion was then used as the mechanical parameter (rotation range).

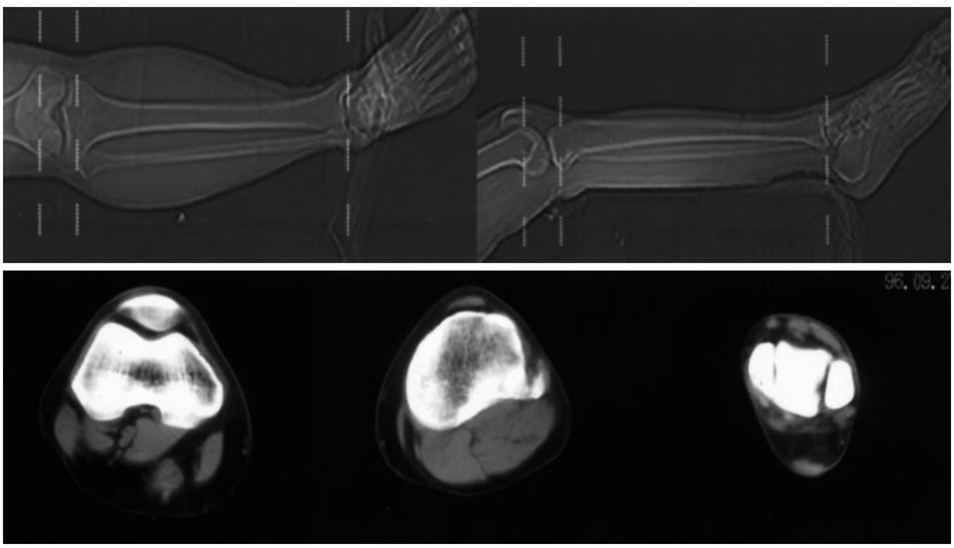

Fig. 2 CT scan was taken at the level of the femoral epicondyle, the tibial tubercle, and the ankle joint in full extension and at 30° of flexion

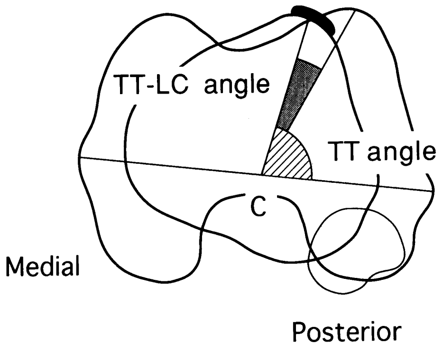

Fig. 3 Schema of tibial tubercle rotation angle (TT angle) and tibial tubercle and lateral condyle angle (TT-LC angle). TT represents the central point of the patellar ligament. LC represents the highest point of the lateral condyle

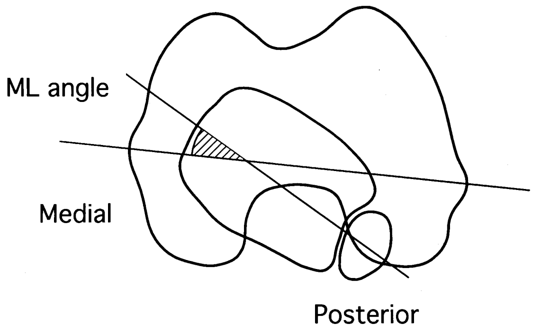

Fig. 4 Schema of malleolar line angle (ML angle). This angle was used to assess the rotation angle of the tibia

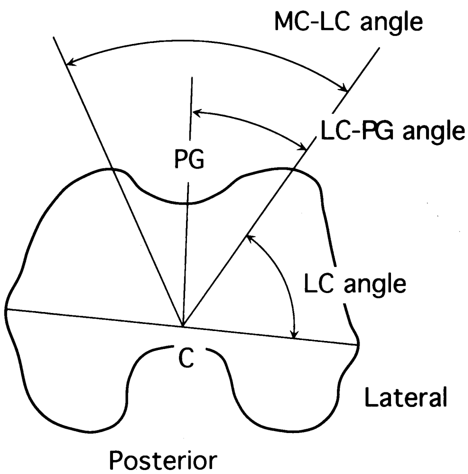

Fig. 5 Schema of lateral condyle angle (LC angle), medial and lateral condyle angle (MC-LC angle), and lateral condyle and patellar groove angle (LC-PG angle). MC represents the highest point of the medial condyle. PG represents the deepest point of the patellar groove. These parameters were used to assess anatomic configurations

Three other parameters – the lateral condyle angle (LC angle), the lateral and medical condyle angle (LC-MC angle), and the lateral condyle–patellar groove angle (LC-PC angle) – were also measured to assess the anatomic configuration of the femoral condyles. The LC angle was the angle between the transepicondylar line and the line from the highest point of the lateral femoral condyle to point C (Fig. 5). The LC-MC angle was the angle between the line from the highest point of the lateral femoral condyle to point C and the line from the highest point of the medial femoral condyle to point C (Fig. 5). The LC-PG angle was the angle between the line from the highest point of the lateral femoral condyle to point C and the line from the deepest point of the patellar groove to point C (Fig. 5). These angles were measured at 30° of flexion but could not be measured at full extension because the patella did not lie in the patellar groove in full extension.

The 12 parameters were compared in the two groups, and a statistical analysis was performed using Student's *t*-test. Difference was considered significant at $P<0.05$.

Results

In full extension, the tibial tubercle was placed in the same position relative to the femoral epicondylar line in both groups. The TT angle was 64.8°±7.5° in the knees with PF-OA and 66.0°±6.5° in the normal knees. The TT-LC angle was 3.3°±6.5° in the knees with PF-OA and 3.9°±6.7° in the normal knees. The rotation angle of the distal tibia (ML angle) was similar in the two groups (18.8°±11.7° and 20.0°±12.5°, respectively). However, the TT-LC angle at 30° of flexion was 9.2°±5.9° in the knees with PF-OA and 15.2°±8.7° in the normal knees (P=0.0161), while the rotation range of the TT-LC angle from full extension to 30° of flexion was 5.9°±5.3° in the knees with PF-OA and 11.3°±7.0° in the normal knees (P=0.0096). The internal rotation of the tibia (ML angle) from full extension to 30° of flexion also significantly decreased in the knees with PF-OA (1.5°±5.0° and 4.9°±5.5°, respectively; P=0.0449). The tibial tubercle in the knees with PF-OA demonstrated a significantly lateral position at 30° of flexion compared with the normal knees, although the position of the tibial tuberle was almost the same in full extension (Table 1).

On the other hand, the LC angle (59.4°±4.3° and 58.5°±5.5°, respectively) and the LC-MC angle (55.4°±5.4° and 56.6°±7.0°, respectively were almost the same in the PF-OA knees and the normal knees. However, the LC-PG angle was 27.0°±3.6° in the knees with PF-OA and 30.0°±4.8° in the normal knees, the difference being statistically significant (P=0.0302) (Table 1).

In the normal group, some volunteers showed abnormal values. For example, the internal rotation of the ML angle in one volunteer was –7°, which meant that the tibia rotated externally during flexion. Although radiography showed no abnormalities, her knee was subclinically abnormal.

Table 1 Results of angle measurements in knees with patellofemoral arthritis (*PF-OA*) and normal knees

	TT angle at extension	TT angle in flexion	TT angle rotation range	TT-LC angle at extension	TT-LC angle in flexion	TT-LC angle rotation range
PF-OA knees	64.8°±7.5°	69.9°±7.0°	5.1°±5.9°	3.3°±6.5°	9.2°±5.9°	5.9°±5.3°
Normal knees	66.0°±6.5°	74.7°±9.6°	8.6°±6.5°	3.9°±6.7°	15.2°±8.7°	11.3°±7.0°
P	0.57	0.08	0.08	0.77	<0.02	<0.01
	ML angle at extension	**ML angle in flexion**	**ML angle rotation range**	**LC angle**	**LC-MC angle**	**LC-PG angle**
PF-OA knees	18.8°±11.7°	17.1°±11.1°	1.5°±5.0°	59.4±4.3°	55.4°±5.4°	27.0°±3.6°
Normal knees	20.0°±12.5°	15.3°±14.2°	4.9°±5.5°	58.5°±5.5°	56.6°±7.0°	30.0°±4.8°
P	0.74	0.66	<0.05	0.59	0.59	<0.04

Discussion

The patella assumes varying positions with knee flexion relative to the femoral condyles. Our previous study showed that varying orientation of the quadriceps muscle did not affect patellar tracking, but tibial rotation did [1]. The position of the tibial tubercle, which varies with flexion, is important in deciding the position of the patella relative to the femoral condyles. Therefore, the position of the tibial tubercle was assessed in the knees with PF-OA in full extension and 30° of flexion in this study. The difference in the values of each parameter in full extension and at 30° of flexion was then used to assess the mechanical influences. Anatomic configurations of the femoral condyles are also important in evaluating patellofemoral disorders. The LC angle, the LC-MC angle, and the LC-PG angle were used to assess the anatomic variations.

In this study, it was important to establish the fiducial point. In some studies in which CT has been used, the femoral posterior condylar line was used as the fiducial line [6], and the CT slice was taken only at one flexion angle in early flexion [2–9]. This line is not reliable when the flexion angle is changed or in knees with femorotibial osteoarthritis. However, the center of knee flexion passes close to the transepicondylar line [10] and therefore this was used as the fiducial line in this study. Great care must be taken to demonstrate the medial epicondyle when the CT scan is made at the level of the femoral epicondyle because the central point of the medial epicondyle is used to draw the epicondylar line.

The other important point was to position the lower extremity in the same position. The lower extremity was positioned on the CT scanner so that the long axis of the tibia was parallel to the CT scanner in the sagittal and coronal planes and the positioning confirmed with a scanogram. If the position can not be obtained, the data will not be reliable.

The results showed that no hypoplasia was observed in the lateral femoral condyle in the knees with PF-OA because the LC angle was similar in the two groups. Therefore, the position of the tibial tubercle was important in deciding the patellar position. In full extension, the tibial tubercle was at a similar position in the two groups. However, inadequate internal rotation of the tibia occurred in the knees with PF-OA when moving from full extension to 30° of flexion. Consequently, the tibial tubercle was positioned significantly laterally at 30° of flexion compared with the normal knees. This finding suggests that the knee with PF-OA has some kind of mechanical abnormality (Fig. 6).

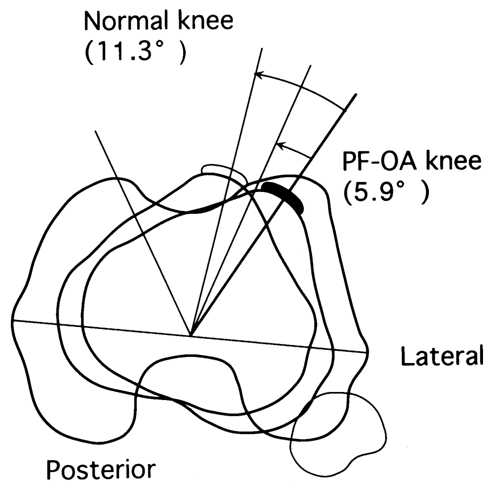

Fig. 6 The tibial tubercle position and the rotation angle of the tibia are similar at full extension in the normal and the PF-OA knees. The tibia in the knees with PF-OA, however, internally rotated inadequately during knee flexion. Subsequently the tibial tubercle is positioned significantly laterally at 30° of flexion in the knees with PF-OA

A laterally positioned tibial tubercle in flexion can be recognized with an axial radiograph. In each knee, a line is drawn on the skin according to the contour of the tibial tubercle and the patellar ligament, and a wire is placed on the skin so that it matches the width of the patellar ligament. An axial view radiograph is taken in 30° of flexion with the Merchant technique. On the radiograph, the wire on the tibial tubercle was positioned laterally in knees with PF-OA (Fig. 7).

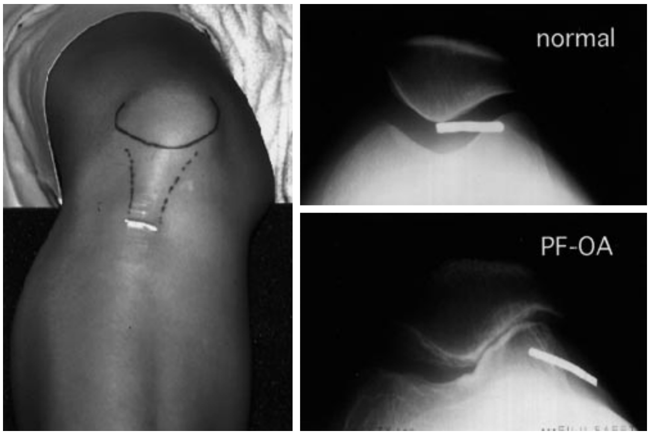

Fig. 7 An axial view radiograph taken at 30° of flexion with the Merchant technique reveals that a wire on the tibial tubercle is located lateral to the femoral lateral condyle in the knees with PF-OA

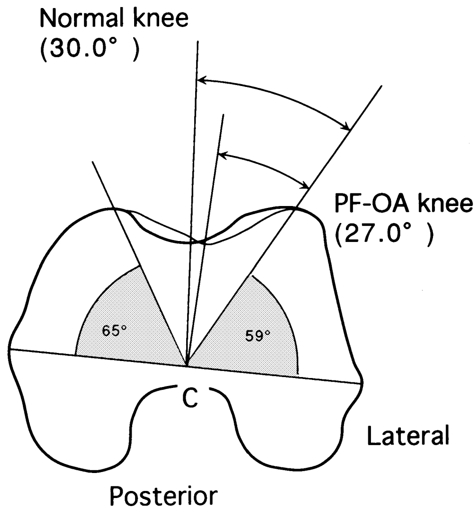

Fig. 8 In the knees with PF-OA, the patellar groove is positioned significantly laterally compared with the normal knees, indicating the articular surface of the lateral femoral condyle is significantly narrower in the knees with PF-OA

Our results also demonstrated that the LC-PG angle was significantly smaller in the knees with PF-OA than in the normal knees. This finding suggests that the articular surface of the lateral femoral condyle may be narrower in knees with PF-OA, or the slope of the articular surface of the lateral femoral condyle may be steeper relative to the transepicondylar line (Fig. 8).

Some knees in the normal group also demonstrated abnormal values. They are thought to be at the risk of developing PF-OA in the future. The CT analysis used in this study can detect positional abnormalities of the tibial tubercle prior to the recognition of abnormalities of the patellofemoral joint by plain radiography or CT. For example, an axial view radiograph only shows the position and shape of the patella with respect to the femoral condyles, and no force applied to the patella can be analyzed on the radiograph. With CT analysis, however, abnormal positioning of the tibial tubercle can be detected, which is useful for analyzing the direction of the force applied to the patella.

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