Malrotation Causing Patellofemoral Complications After Total Knee Arthroplasty

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Thirty patients with isolated patellofemoral complications after total knee arthroplasty were compared with 20 patients with well functioning total knee replacements without patellofemoral complications. The epicondylar axis and tibial tubercle were used as references on computed tomography scans to measure quantitatively rotational alignment of the femoral and tibial components. The group with patellofemoral complications had excessive combined (tibial plus femoral) internal component rotation. This excessive combined internal rotation was directly proportional to the severity of the patellofemoral complication. Small amounts of combined internal rotation $(1^{\circ}-4^{\circ})$ correlated with lateral tracking and patellar tilting. Moderate combined internal rotation $(3^{\circ}-8^{\circ})$ correlated with patellar subluxation. Large amounts of combined internal rotational (7°-17°) correlated with early patellar dislocation or late patellar prosthesis failure. The control group was in combined external rotation (10°-0°). The direct correlation of combined (femoral and tibial) internal component rotation to the severity of the patellofemoral complication suggests that internal component rotation may be the predominant cause of patellofemoral complications in patients with normal axial alignment. The epicondylar axis and tibial tubercle are reproducible landmarks which are visible on computed tomography scans and can be used intraoperatively. Using this computed tomography study can determine whether rotational malalignment is present and thus, whether revision of one or both components may be indicated.

Total knee arthroplasty has become the standard treatment for various disabling disorders of the knee and has proven long term success.^{7,14,17,18,24} Surgical technique and prosthetic design have evolved to produce consistent and excellent results.^{17,26} Despite the current success of total knee arthroplasty, complications remain. Patellofemoral complications are the most common postoperative problem associated with the current design of total knee prostheses and are currently the major cause for revision surgery.^{1,6,9,12,13,15,19,20,22,23,25}

In the absence of axial malalignment, some authors have indicated qualitatively that patellofemoral complications are associated with improper rotation of the femoral and tibial components.^{5,10,11,16,17} However, these qualitative reports lack specific measurement

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of component rotation based on generally accepted landmarks. No correlation between the amount of rotational malalignment and the type of patellofemoral complications in total knee arthroplasty has been shown. In addition, if rotational malalignment was responsible for patellofemoral complications, then more severe rotational malalignment should lead to more severe patellofemoral complications. Therefore, the purpose of the present investigation was twofold. First, develop a technique to measure quantitatively femoral and tibial component rotational alignment using a standard computed tomography (CT) scanner. Second, apply this technique to two groups; a control group of patients with well functioning total knee replacements and a study of a group of patients with documented stable, sterile, and axially well aligned knee prosthetic components who were undergoing revision total knee arthroplasty for isolated patellofemoral problems.

MATERIALS AND METHODS

The study group consisted of patients undergoing revision total knee arthroplasty for patellofemoral problems. Patients with infection or loose tibial or femoral components at the time of surgery were excluded. Patients with documented axial malalignment, defined as mechanical alignment outside the range from 1° varus to 2° valgus, also were excluded. Using this criteria, 30 patients undergoing revision total knee arthroplasty for isolated patellofemoral complications were included in this prospective study. This cohort of 30 patients included 16 men and 14 women with an average age of 69 years. The 30 index procedures were performed by eight different surgeons. A control group of 20 patients with well functioning total knee arthroplasties were chosen from the authors' group practice. These patients had normal axial alignment and no patellofemoral problems.

Preoperative CT scans were obtained to determine the rotation of the tibial and femoral components. This technique is applicable to any CT scanner. The patient was placed supine on the CT scanning table with the involved extremity in full extension with the extremity adjusted to allow the scans to be perpendicular to the mechanical axis of the knee (Fig 1). Using the lateral scout view, the scans were taken perpendicular to the long axis of the femur for the femoral scan and perpendicular to the long axis of the tibia for the tibial scans (Fig 2). This was achieved by tilting the scanner's gantry. Computed tomographic images 1.5 mm in thickness were obtained at four locations: through the epicondylar axis on the femur, though the tibial tubercle, through the top of the tibial plateau, and through the tibial component (Figs 1, 2).

The rotation of the femoral component was determined using the single axial CT image through the femoral epicondyles² (Fig 3). On this CT image, two lines are drawn (Fig 4). The first line, the surgical epicondylar axis, connects the lateral epicondylar prominence and the medial sulcus of the medial epicondyle.² The second line, the prosthetic posterior condylar line, connects the medial and lateral prosthetic posterior condylar surfaces.² The angle subtended by these two lines, the prosthetic posterior condylar angle, then was measured.

To determine whether the femoral component is in excessive internal or external rotation, the normal posterior condylar angle was used.^{2,4} The na-



Fig 1. The anteroposterior scout view obtained in the CT scanner. The scans are perpendicular to the mechanical axis of the knee. Images of 1.5 mm in thickness were obtained through the epicondylar axis on the femur (Line +7), through the tibial tubercle (Line +24), through the top of the tibial plateau (Line +17), and through the tibial component (Line +13). R = right; L = left. **Fig 2.** The lateral scout view obtained in the CT scanner. The scans were taken perpendicular to the long axis of the femur for the femoral cut and perpendicular to the long axis of the tibia for the tibial cuts. This is achieved by tilting the scanner's gantry. As in Figure 1, 1.5-mm thick images were obtained through the epicondylar axis on the femur (Line +7), through the tibial tubercle (line +24), through the top of the tibial plateau (Line +17), and through the tibial component (Line +13).

tive rotation value for the posterior condylar angle is 0.3° (± 1.2°) internal rotation for females and



Fig 3. Line drawing of the cross section of the femur through the epicondylar axis. The surgical epicondylar axis connects the lateral epicondylar prominence and the medial sulcus of the medial epicondyle. The posterior condylar line connects the medial and lateral posterior condylar surfaces. The posterior condylar angle is the angular measurement subtended by these two lines. (Reprinted and adapted with permission from Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS: Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. Clin Orthop 286:40–47, 1993.)



Fig 4. Axial CT image of the right femur through the epicondylar axis (Line +7 on the scout views shown in Figures 1 and 2). Compare this view with Figure 3. The surgical epicondylar axis (S.E.A.) connects the lateral epicondylar prominence and the medial sulcus of the medial epicondyle. The posterior condylar line (P.C.L.) connects the medial and lateral prosthetic posterior condylar surfaces. Deg = degrees.

 3.5° (± 1.2°) internal rotation for males relative to the surgical epicondylar axis.^{2,4} A case example follows to illustrate the method used to determine the femoral component rotational angle.

Case Example; Femoral Component:

Figure 4 shows the right knee of a female patient. First, the surgical epicondylar axis (S.E.A.) is shown connecting the lateral epicondylar prominence and the medial sulcus of the medial epicondyle. This line is positioned 0° to the horizontal. Second, the prosthetic posterior condylar line (P.C.L.) is shown connecting the medial and lateral prosthetic posterior condylar surfaces. This is positioned 5° (internal) to the horizon. The angle between these two lines is 5°. This indicates that the femoral component is 5° internally rotated relative to the surgical epicondylar axis. In females the normal posterior condylar angle is $0.3^{\circ} (\pm 1.2^{\circ})$ internal rotation; therefore, the femoral component is in 4.7° excessive internal rotation as compared with the surgical epicondylar axis.

To determine rotation of the tibial component, the geometric center of the proximal tibial



Fig 5A–B. (A) Axial CT image through the proximal tibial plateau, just distal to the tibial plateau. The CT scanner oval that is sized and rotated to best fix the proximal plateau is shown. The center of the oval is marked automatically by the computer. (B) Axial CT image through the tip of the tibial tubercle. The geometric center (G.S.) of the tibial plateau then was transposed distally to this image. The tibial tubercle orientation is defined by the line connecting the geometric center of the tibial plateau to the tip of the tibial tubercle. This line is at 21° external rotation (referenced to the vertical) as measured on the CT scan. Deg = degrees.

plateau was located (Fig 5A) and axially transposed distally to the level of the tibial tubercle (Fig 5B). Then the geometric center of proximal tibial plateau and the tip of the tubercle are connected giving the orientation of the tubercle (Fig 5B). The anteroposterior (AP) tibial component axis is drawn on the single axial scan through the tibial component (Fig 6A). The tibial component rotation is subtended by the orientation of the tibial tubercle and the AP tibial component axis³ (Fig 6B).

To determine whether the tibial component is in excessive internal or external rotation, the normal relationship between the orientation of the tibial tubercle and the tibial articular surface was used.³ The normal rotation value for the tibial component, which corresponds to the native articular surface, is $18^{\circ} (\pm 2.6^{\circ})$ internal rotation from the tip of the tubercle. A case example follows to illustrate the method used to determine the tibial component rotational angle.

Case Example; Tibial Component:

The geometric center of the tibial plateau obtained in Figure 5A is transposed to Figure 5B. In Figure 5B, a line connecting the geometric center (G.S.) to the tip of the tibial tubercle denotes the tibial tubercle axis. On Figure 6A, the AP tibial component axis (T.C.A.) is drawn perpendicular to the posterior surface of the component. Figure 6B shows the tibial component axis (T.C.A.) from Figure 6A with the superimposed orientation of the tibial tubercle axis from Figure 5B. This angle measures 23° internal rotation. The normal value for this angle is 18° . Therefore, the tibial component is in 5° excessive internal rotation.

For each patient the excessive rotation of the tibial and femoral components were calculated as described above. The combined component rotation for each patient was obtained by adding the femoral component rotational angle and the tibial component rotational angle for each patient. Internal rotation of either the femoral component or the tibial component was added as a negative (-) angle. External rotation of either component was added as a positive (+) angle.

RESULTS

In the group of patients with isolated patellofemoral problems, the preoperative mechanical axis of the knee, determined from long leg standing radiographs, ranged from



Fig 6A–B. (A) Axial CT image through the tibial component polyethylene. The tibial component axis (T.C.A.) was defined as the perpendicular (2) to the transverse axis of the tibial component (1). For this rectangular tibial component, the tibial component axis is perpendicular to the posterior margin of the component. This line is at 2° internal rotation (referenced from the vertical) as measured on the CT scan. Deg = degrees. (B) Axial CT image through the tibial component polyethylene. The tibial tubercle orientation from Figure 5A is superimposed on the tibial component axis (T.C.A.) from Figure 6A. The rotation of the tibial component is recorded as the angle subtended by the tibial tubercle axis (2) and the tibial component axis (T.C.A.) (1). The difference is 23°, indicating the rotation of the tibial component is 23° internal rotation relative to the tibial tubercle.

1° varus to 2° valgus (average, 0.6° valgus ± 0.5°). The anatomic axis ranged from 5 to 8° valgus (average, 6.7° valgus $\pm 0.5^{\circ}$). The component types were as follows: 10 were Porous Coated Anatomic (Howmedica, Rutherford, NJ); nine, Miller-Galante I (Zimmer, Warsaw, IN); four, Natural knees (Intermedics, Austin, TX); four, Miller-Galante II (Zimmer); and three, Insall-Burstein II (Zimmer). This distribution of posterior cruciate retaining and posterior cruciate substituting prostheses also was similar to the distribution of primary total knee replacements among patients throughout the community. All of the control knee replacements were posterior cruciate ligament retaining knee replacements; 12 Miller-Galante II (Zimmer); five, Miller-Galante I (Zimmer); and three, ACG knees (Biomet, Warsaw, IN). In the control group, the mechanical axis of the knee ranged from 1° varus to 2° valgus and the anatomic axis ranged from 5° to 8° valgus.

The final diagnoses of the 30 patients with patellofemoral problems were categorized as follows: lateral patellar tracking and tilt occurred in five patients, patellar subluxation occurred in eight patients, patellar dislocation occurred in seven patients, and patellar prosthesis failure occurred in 10 patients. In the patients in whom the patellar prosthesis failed, there were five failures at the cement interface, two cases showed shearing off of the polyethylene pegs, two cases had polyethylene metal debondings, and one case had a patellar fracture. At the time of revision, no infection was present and all patients had solidly fixed tibial and femoral components. There was no correlation between age, gender, component type, index surgeon, manufacturer, or axial alignment to the type of patellofemoral complication.

Considering the entire group of 30 patients with isolated patellofemoral complications, the rotation of the femoral component

Diagnosis	Years After Primary Total Knee Arthroplasty	Femoral (°)	Tibial (°)	Overall Component (internal rotation) (°)
Lateral track and tilt	4	0		
Lateral track and tilt	0.5	-2	, O	-2
Lateral track and tilt	1.5	-1	-2	-3
Lateral track and tilt	2.5	-1	-2	-3
Lateral track and tilt	2	Ó	-4	-4
Subluxation	4	-4	+1	-3
Subluxation	2.5	0	-4	-4
Subluxation	1.5	+2	-6	-4
Subluxation	3	+1	-7	6
Subluxation	1	0	-7	-7
Subluxation	3.5	-3	-4	-7
Subluxation	2	-3	5	-8
Subluxation	2.5	-8	0	-8
Dislocation	1	-2	-5	-7
Dislocation	1	-3	-5	-8
Dislocation	1.5	-3	-6	9
Dislocation	0.5	-2	-8	-10
Dislocation	1	-3	-10	-13
Dislocation	1.5	-3	-12	-15
Dislocation	0.5	-1	-15	-16
Prosthesis failure	2	-3	-5	-8
Prosthesis failure	6	-6	-3	-9
Prosthesis failure	3	-4	-6	-10
Prosthesis failure	4.5	-3	-7	-10
Prosthesis failure	3	0	-12	-12
Prosthesis failure	6	-4	-8	-12
Prosthesis failure	5	-3	-10	-13
Prosthesis failure	4	-4	-11	-15
Prosthesis failure	3.5	-6	-10	-16
Prosthesis failure	3	-6	-11	-17

TABLE 1. Data for Component Rotation

ranged from 2° excessive external rotation to 8° excessive internal rotation (Table 1). The rotation of the tibial component ranged from 1° excessive external rotation to 15° excessive internal rotation (Table 1). The combined component rotation, obtained by adding the excessive tibial component rotation and the excessive femoral component rotation, ranged from 1° to 17° excessive internal rotation (Table 1). This was statistically significant when compared with combined component rotation in the 20 patients in the control group. The control group was in combined excessive external rotation, ranging from 10° to 0° (p < 0.0001, analysis of variance [ANOVA]).

In the 30 patients with patellofemoral complications, the combined excessive internal component rotation was found to correlate directly with the severity of the patellofemoral complication (p < 0.01, ANOVA). The five patients with the objective finding of lateral tracking and tilting had combined component rotation ranging from 1° to 4° excessive internal rotation. The eight patients with the objective finding of subluxation had combined component rotation ranging from 3° to 8° excessive internal rotation. The seven patients with dislocation had combined component rotation ranging from 7° to 16° excessive internal rotation, and the 10 patients with prosthesis failure had combined component rotation ranging from 8° to 17° excessive internal rotation. Analyzing the femoral and tibial components individually, there was only a trend toward excessive internal component rotation relating to the severity of patellofemoral complication. This was not statistically significant. Only when combining tibial and femoral components was the severity of the patellofemoral components was the severity of the patellofemoral component complication statistically related to the combined excessive internal component rotation (p < 0.01, ANOVA).

The time between index arthroplasty and first presentation with symptoms also is included in Table 1. The patients with combined component rotation ranging from 1° to 4° excessive internal rotation presented between 6 months and 4 years from the time of total knee arthroplasty. The patients with combined component rotation ranging from 3° to 8° excessive internal rotation presented between 1 year and 4 years from the index arthroplasty. Finally, patients with combined component rotation ranging from 7° to 17° excessive internal rotation had component dislocation before 2 years or prosthesis failure after 3 years. Figure 7 shows the relationship of excessive combined component rotation and the time after index arthroplasty when the patient first had patellofemoral complications develop. The same relationship data are shown in the control group. The five groups are clustered (Fig 7). Using an ANOVA statistical analysis based on degrees of combined rotation and years after index procedure, all five groups are statistically distinct (p < 0.01).

DISCUSSION

Evolution of surgical technique, prosthetic design, and instrumentation in total knee arthroplasty has made total knee replacement a reliable and durable surgical procedure.^{7,14,17,18,24} Despite significant advancements, patellofemoral complications remain the most common postoperative problem associated with current total knee arthroplasties.^{1,12,15,23,25}

Proper axial alignment has been recognized as an important factor influencing the



Fig 7. Graph showing the relationship of combined component rotation to the time that each patient first had patellofemoral complications develop. Thirty patients with isolated patellofemoral complications after total knee arthroplasty are in combined excessive internal rotation. These 30 patients are clustered into four groups by type of patellofemoral complication. In addition, severity of the patellofemoral complication increases with increasing combined excessive internal rotation. The control group of 20 well functioning total knee replacements without patellofemoral complications are in combined excessive external rotation.

outcome of total knee arthroplasty.^{10,11} In the present study, the anatomic axis of the knee ranged from 5° to 8° valgus and the mechanical axis of the knee ranged from 1° varus to 2° valgus, both values being well within the generally accepted range of normal values. Thus, the isolated patellofemoral complications occurring after total knee arthroplasty in the patients in this study occurred in the setting of correct axial alignment.

Although Figgie and associates^{10,11} outlined criteria for proper axial alignment in total knee arthroplasty, they concluded that tibial component rotation is the most important factor for patellofemoral tracking. They attributed patellar fracture to improper rotational alignment of either the tibial component or the femoral component. The results described by Figgie et al^{10,11} agreed with earlier reports in which Merkow et al¹⁶ and Ranawat¹⁷ concluded that patellar dislocation, subluxation, tilt, and excessive patellar wear result from malrotation of the tibial and femoral components. More recently, Briard and Hungerford⁵ concluded that malalignment of any component can lead to patellofemoral instability and subsequent dislocation.

Although many authors have cited tibial or femoral component rotation as an important variable in total knee arthroplasty, quantitative analysis has been lacking.5,8,10,16,17,21,24 To date, this subjective measure of component rotation only could be obtained at the time of revision surgery.^{5,7,16,21,24} In contrast to axial alignment measurements that can be obtained readily from standing long leg radiographs, an analogous diagnostic test to quantify rotational alignment preoperatively was not available. The lack of an available diagnostic test led to the development of a CT scanner protocol designed to quantify rotational alignment measurements. This protocol is based on the surgical epicondylar axis and the tibial tubercle, anatomic landmarks previously shown to be accurate and reproducible for rotational angular measurements.²⁻⁴ This technique provides a noninvasive method for quantitatively determining the rotational alignment of the tibial and femoral components on any standard CT scanner. The values resulting from this method have been shown to be a reliable measurement of the tibial and femoral component rotation.^{2–4} These qualities allow this CT protocol to be used to assess rotational alignment quantitatively in any malfunctioning total knee arthroplasty.

The application of this technique to the study of 30 patients undergoing revision total knee arthroplasty for patellofemoral symptoms without loosening, infection, or axial malalignment has suggested several findings. All of the patients were symptomatic and all had some degree of excessive combined internal rotation. This was in contrast to the combined excessive external rotation observed in the knees of the 20 patients without patellofemoral problems. In the patients with patellofemoral complications, the amount of excessive combined internal component rotation was directly proportional to the severity of the patellofemoral complication (p < 0.01). Relatively small amounts of combined excessive internal component rotation, from 1° to 4°, correlated with the objective problem of lateral tracking and tilting and the subjective problem of pain. Overall component rotation ranging from 3° to 8° excessive internal rotation correlated with the objective finding of patellar subluxation. Overall component rotation ranging from 7° to 17° excessive internal rotation correlated with findings of early patellar dislocation and late patellar prosthesis failure. The direct relationship of excessive combined internal component rotation to the severity of the patellofemoral complication indicates that component malrotation may be the predominant cause of patellofemoral problems in this group of patients.

The two groups with the most severe problems of patellar dislocation and patellar prosthesis failure were of particular interest. Although both groups presented with a large amount of excessive combined internal component rotation, the patients with dislocations presented early, before 2 years, whereas the patients in which the prosthesis failed presented later, after 2 years. In addition, the results show that the femoral component of the patients in whom dislocation occurred was in more external rotation than the femoral component of the patients in whom the patellar prosthesis failed. With a large, combined, excessive internal component rotation, more femoral component external rotation may cause a relative lowering of the prosthetic lateral flange providing less constraint to the patella in the trochlear groove leading to patellar dislocation. This dislocation occurs soon after the index arthroplasty as the soft tissues become incompetent with more than 7° or 8° excessive internal rotation. Conversely, with a large, combined, excessive internal component rotation, more femoral component internal rotation effectively raises the lateral flange that acts as a barrier to dislocation. The patella, therefore, is more constrained and dislocation does not occur. In this situation, the patellar prosthesis is subjected to high shear forces with time resulting in patellar prosthesis failure after many years of use.

Although this study does not show which component is more important to combined rotational alignment, both components seem to be important. Component type, manufacturer, and surgeon did not correlate with the severity of patellofemoral complication. The distribution of manufacturers and prosthetic designs was similar to that used in primary cases. In addition, with eight surgeons involved in these index procedures, it is doubtful that surgical technique, which includes soft tissue tensioning or lateral release, was as important as combined rotation in causing patellofemoral complications.

Because this investigation was undertaken with knees with patellofemoral problems, the authors are unable to say conclusively that all knees with excessive internal rotation have patellofemoral complications develop or that all knees with isolated patellofemoral complications have excessive internal rotation. Only the results of a long term, prospective study will be able to conclude this. However, in this series, all the knees with isolated patellofemoral complications had excessive combined internal rotation. The severity of the patellofemoral complication was proportional to the excessive combined component internal rotation, indicating that component rotation is an important factor in these patellofemoral problems.

This investigation reports a technique to measure quantitatively femoral and tibial component rotational alignment in total knee arthroplasty. The application of this technique to 30 patients undergoing revision total knee arthroplasty for patellofemoral symptoms without loosening, infection, or axial malalignment confirms the concept that rotational alignment of the tibial and femoral components must be addressed in primary and revision total knee arthroplasty. This study showed that increasing amounts of excessive internal rotational malalignment resulted in more severe patellofemoral complications, whereas knees without patellofemoral problems were in combined external rotation. This study validates the epicondule axis and tibial tubercle as excellent landmarks to assess rotation. These landmarks easily are used intraoperatively to rotate the femoral and tibial components. From this data, femoral components should be aligned to the epicondylar axis and tibial components should be aligned 18° from the tibial tubercle. This combined rotation resulted in normal patellofemoral tracking.

Rotational malalignment may result in a malfunctioning total knee arthroplasty without loosening, infection, or axial malalignment. Therefore, in patients who present with a malfunctioning total knee arthroplasty and patellofemoral pain in an otherwise well aligned, well fixed, and sterile total knee arthroplasty, rotational malalignment should be suspected. In these instances, the noninvasive CT scanner protocol can accurately confirm the diagnosis and aid in the planning of revision surgery.

Although this CT study is relatively inexpensive, under \$200.00, it should not be performed if radiographic evidence is obvious for axial malalignment or component loosening. In the absence of conclusive radiographic evidence, this CT study can determine whether rotational malalignment is present and thus, whether revision of one or both components may be indicated. This study is well tolerated by patients, is noninvasive, relies on easily available technology, and is easy to perform. Any design of component can be analyzed by this technique; although a titanium prosthesis provides the clearest CT image because of its low scatter. The test can be used any time after implantation and before or after revision. Currently, this CT study is recommended on patients with isolated patellofemoral complications in which the cause is not evident.

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