"Grand Piano Sign," a Marker for Proper Femoral Component Rotation During Total Knee Arthroplasty

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Abstract

A malpositioned femoral component is an established risk factor for patellar instability and pain after total knee arthroplasty (TKA). In the assessment of femoral rotation, several axes, including the transepicondylar axis, the posterior condylar axis, and the anteroposterior axis, are useful. However, these axes are not always easily applicable, particularly when significant deformity exists.

An anecdotal method used by some surgeons involves assessing the shape of the anterior femoral surface osteotomy. Our observations from saw bone models and TKA led to our hypothesis that proper femoral component placement is indicated by a bimodal peak on the anterior femur, approximately twice as high on the lateral side than on the medial side. We use the term "grand piano sign" to describe the shape of the trochlea after the osteotomy is correctly completed.

To our knowledge, this common observation has not been studied either in the laboratory or in vivo. Our cadaveric models demonstrated that the grand piano sign correlated with proper femoral rotation during TKA. Surgeons who are knowledgeable about this marker should find it helpful when orienting components during knee replacement surgery.

It is well established that malrotated femoral components are a major risk factor for postoperative patellofemoral problems, such as instability and poor tracking. The rate of patellar femoral joint complications after total knee arthroplasty (TKA) has been estimated to be higher than 10%, and these complications remain a leading cause of poor outcomes after TKA.[1-4]

Several preventable causes of patellar instability and pain have been identified. These include use of an excessively thick patellar button ("overstuffing"), failure to release a tight lateral retinaculum, and rotational malalignment of the femoral or tibial components.[4,5] In a study of more than 100 TKAs, the incidence of anterior knee pain was 5 times higher in knees in combined prosthetic internal rotation than in knees in external rotation.[6]

Several axes, including the transepicondylar axis (TEA), the posterior condylar axis (PCA), and the anteroposterior (AP) axis, are commonly used in an attempt to achieve correct femoral component rotation. It is thought that both the TEA and the AP axis are more accurate than the PCA, particularly in the valgus knee.[1,6] Although these methods often may be useful, they are not always easily identified or universally applicable in the operating room.[7-9] In addition, accuracy of the TEA, the PCA, and the AP axis is negatively affected by significant deformity.[1]

Another method of assessing correct femoral component rotation during TKA involves evaluating the shape of the trochlea after the anterior osteotomy has been performed. This "grand piano sign" has been observed by other authors,[2] but has not been studied either during surgery or in the laboratory setting. Our goal in the present study was to measure how rotation of the femoral osteotomy affects the shape of the anterior femur during TKA.

Before conducting this study, we used saw bone models to evaluate the grand piano sign in relation to measured rotation of various degrees. Our observations from these saw bones, and the intraoperative findings, led us to hypothesize that correct rotation of the femoral cutting block in cadaver specimens should yield a bimodal peak on the trochlea. Furthermore, the resultant lateral peak on the anterior femur should be approximately twice that on the medial side.

Materials and Methods

Eighteen embalmed knees from 9 cadavers were obtained from the anatomical donation program at our institution. Specimens were deemed appropriate for inclusion if they demonstrated a bimodal shape on the anterior femur with measurable medial and lateral peaks. Notched specimens having a unimodal shape and only one peak on the anterior femur were excluded from analysis. The cadaver knees were dissected free of all tissues, except for the footprint of the medial and lateral collateral ligament origins on the femur.

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Table I. Femoral Resection Block Sizing for Cadaveric Specimen Knees

Knees	Block Size[a]
1, 2	7
3, 4	13
5, 6, 9-14	9
7, 8	11

[a]A standard total knee instrumentation set was used to match the native anatomy of the cadaver knee.

Table II. Rotational Differences Among Cadaveric Specimens

	Deviation From, °		
Knee	TEA	PCA	M:L Ratio, mm
1	3.5 IR	0.2 IR	20/50 = 0.40
2	0.9 IR	3.3 ER	33/56 = 0.59
3	1.7 IR	1.9 ER	32/50 = 0.64
4	8.5 IR	4.4 IR	15/17 = 0.88
5	3.5 IR	0.1 ER	24/35 = 0.69
6	1.1 IR	3.8 ER	27/46 = 0.59
7	1.2 IR	2.9 ER	31/41 = 0.76
8	8.5 IR	4.7 IR	35/34 = 1.03
9	5.1 IR	0.1 IR	25/38 = 0.66
10	2.8 IR	2.0 ER	15/38 = 0.39
11	0.5 IR	2.8 ER	12/28 = 0.43
12	13.8 IR	11.0 IR	31/15 = 2.07
13	2.2 ER	9.3 ER	35/57 = 0.61
14	3.4 IR	2.7 ER	37/48 = 0.77

Abbreviations: ER, external rotation; IR, internal rotation; L, lateral peak height; M, medial peak height; PCA, posterior condylar axis; TEA, transepicondylar axis.

Table III. Anatomic Variation Between the PCA and TCA

	TEA	PCA	M:L Ratio
Total no. of specimens	14	14	14
Maximum IR, ° from	2.07	13.80	11.00
Maximum ER, ° from	2.20	9.30	0.39
Mean rotation, ° from	3.74 IR	0.60 ER	0.75
SD, °	4.12	4.81	0.42

Abbreviations: ER, external rotation; IR, internal rotation; L, lateral peak height; M, medial peak height; PCA, posterior condylar axis; SD, standard deviation; TEA, transepicondylar axis.

A standard total knee instrumentation set (Howmedica Osteonics; Stryker Orthopaedics, Mahwah, New Jersey) with femoral cutting blocks from size 5 to 12 were used to match the native anatomy of the cadaver knee (Table I). A posterior referencing system identical to what we use in the operating room was used for this experiment.

After the distal femur was exposed, a .375-in (3/8-in) hole was drilled at the anterior margin of the intercondylar notch, approximately 1 cm anterior to the posterior cruciate ligament origin. An intramedullary rod was inserted and assembled to the distal femoral resection block in 7° of valgus. Eight millimeters of distal femur was resected to allow for later placement of the femoral cutting block onto the distal femur.

Next, the AP sizing guide with stylus was used to allow for correct sizing of the cadaver specimens. The femoral sizing guide (Howmedica Osteonics, Stryker Orthopaedics) has 4 pin holes that allow for placement of the cutting block in either 0° or 3° of external rotation from the posterior condyles. All knees were found to have intact posterior condyles, without significant loss of cartilage or bone.

Of the 18 specimens, we cut 9 in the recommended 3° of external rotation from the PCA using the built-in 3° holes on the femoral cutting guide. The other 9 were osteotomized with increasing amounts of internal or external rotation by overrotating the cutting block clockwise or counterclockwise. We continued to overrotate each specimen until notching occurred. Once the resection block was secured, the anterior chamfer osteotomy was performed, and then the distal femur specimens were detached at the metaphyseal flare for later measurement.

Of the 18 knees, 14 had a bimodal shape on the anterior femur after resection. Their respective medial (M) and lateral (L) peak heights were measured and recorded, and then M:L ratios were calculated to determine whether the ratio correlated with either the TEA or the PCA (Table II).

Four of the 18 knees were notched from excessive overrotation of the cutting block. This notching was anticipated, as the study protocol involved excessive, purposeful overrotation of the cutting guide in half the specimens in order to measure the effects of malrotation on the shape of the grand piano sign. In accordance with our predetermined exclusion criteria, these 4 specimens were dropped from this analysis.

Before conducting the study, we excluded the 4 notched specimens to eliminate any measurement bias. It was important to remove these outliers because notching creates an uneven horizontal stepoff, without an obvious bimodal peak on the anterior femur. In con-

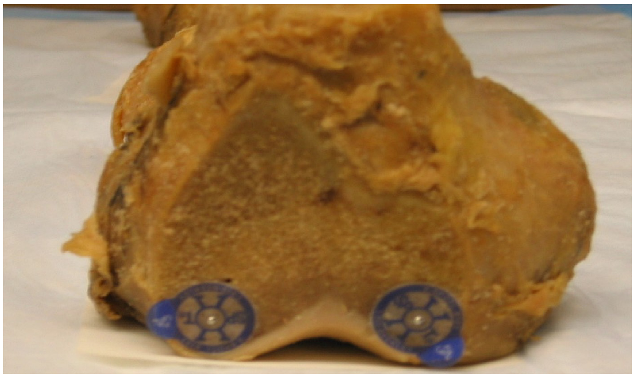

Figure 1. Cadaver specimen has typical appearance of "grand piano sign." Radiographic markers were placed distally on flat surface of anterior femoral resection to facilitate radiographic measurement of femoral resection rotation.

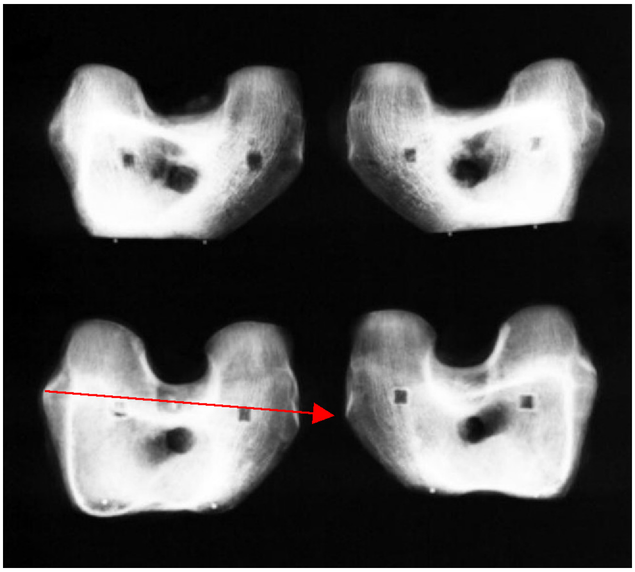

Figure 2. Radiograph shows femoral epicondyles. Radiographic markers on anterior surface of femur were used to compare and measure amount of femoral rotation after resection to transepicondylar axis.

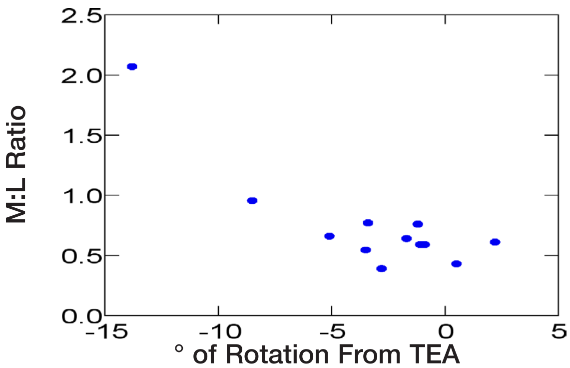

Figure 3. Graph of ratios of medial peak height (M) to lateral peak height (L) plotted against transepicondylar axis (TEA).

trast, unnotched femurs have well-defined peaks with smooth, pointed tips on the cut surface of the trochlea, which are required to accurately measure the height of each true peak.

For each specimen, axial radiographs were obtained. A Faxitron machine (Faxitron X-Ray, Lincolnshire, Illinois) set at 12 seconds of exposure and 32 Kv was used. Before the film was developed, radiopaque Beekley spot markers (Beekley, Bristol, Connecticut) were placed distally on the lateral and medial halves of the anterior femur chamfer resections (Figures 1, 2).

The radiographs were digitally scanned, and measurements were made with imaging software provided by the department of radiology at our institution.

The TEA, the PCA, and the degree of external or internal rotation, as determined by a line connecting the radiopaque markers on the anterior chamfer resections, were then readily measured (Figure 2).

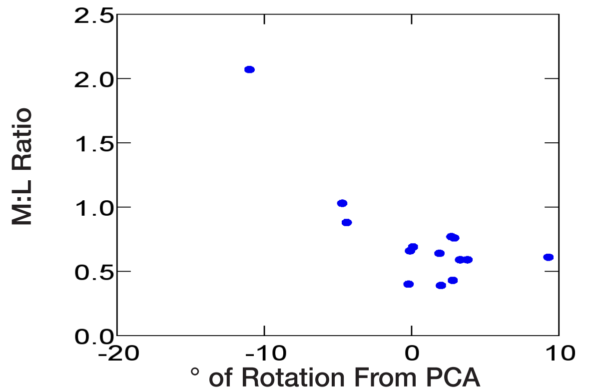

Figure 4. Graph of ratios of medial peak height (M) to lateral peak height (L) plotted against posterior condylar axis (PCA).

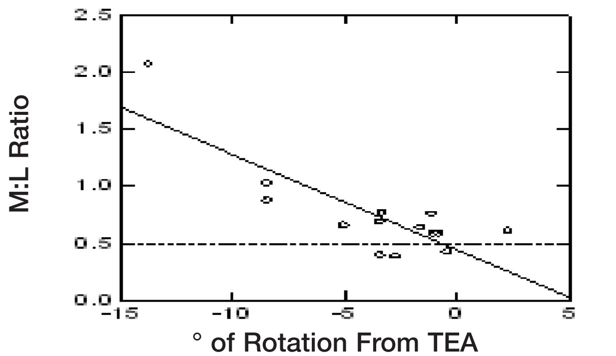

Figure 5.. Regression line of ratio of medial peak height to lateral peak height (M:L ratio) and transepicondylar axis (TEA). Arrow points to where regression line intercepts 0.5 M:L ratio. As M:L ratio approaches 0.5, femur specimens were rotated in line with TEA.

Statistics

Descriptive statistics were computed for the PCA, the TEA, and the M:L ratio (Table III). Normality was assessed with normal probability plots and the Kolmogorov-Smirnov test. Linear regression models were also used to model the relationship between the markers of femoral rotation and the M:L ratio. M:L ratio was used as the independent variable in this model; the dependent variable was the marker of femoral rotation, which was measured in degrees of rotation from both the PCA and the TEA. The regression equations were inverted to find the angles corresponding to an M:L ratio of 0.5.

Results

The data obtained for each knee—including the M:L ratio and the degree of rotation of the femoral osteotomy from the TEA and the PCA—are represented in Table II. Graphs were constructed with each M:L ratio plotted on the y-axis and the degrees of femoral rotation on the x-axis (Figures 3, 4). Linear regression performed on these data yielded an *r* of 0.82 for the TEA (P<.0001) and an *r* of 0.78 for the PCA (P<.001).

The graphic data show that several of the femoral osteotomies were within a few degrees of the TEA.

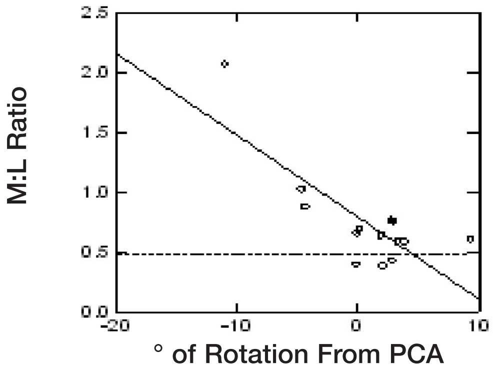

Figure 6. Regression line of ratio of medial peak height to lateral peak height (M:L ratio) and posterior condylar axis (PCA). M:L ratio of 0.5 corresponds to approximately 4° of external rotation from PCA.

Furthermore, the M:L ratio of 0.5 was found to intercept the regression line within 1° of the TEA (Figure 5). In other words, when the femoral osteotomy matched the TEA, the lateral peak on the trochlea was approximately twice the height of the medial peak. This is in agreement with our hypothesis that correct femoral rotation should yield a bimodal shape on the anterior femur with an M:L ratio of approximately 0.5.

The graphic data also demonstrate that, as the amount of internal rotation increases, the M:L ratio exceeds the value of 1. This means that, as the amount of internal malrotation increases, the medial peak on the anterior femur approaches and eventually exceeds the height of the lateral side, and thus the grand piano sign becomes reversed (Figures 3, 4).

In addition, the trends are similar when comparing the femoral osteotomies with the PCA. The point where the M:L ratio of 0.5 intercepts the regression line is at 4.3° of external rotation from the PCA (Figure 6).

Last, descriptive statistics were analyzed to evaluate the amount of rotation between the PCA and the TEA. Mean difference between PCA and TEA was 4.3° (range, 2.8°-6.1°) (Table III).

Discussion

Several authors have purposed the correct or ideal rotation of the femoral component during TKA.[1,10,11] The results from our cadaver study support our hypothesis that correct rotation leads to a bimodal shape on the anterior femur, with the lateral peak approximately twice the height as the medial peak. Specifically, an optimal grand piano sign with an M:L ratio of approximately 0.5 can be observed when the osteotomy is in line with the TEA or when it is 4.3° externally rotated from the PCA (Figures 5, 6).

Another interesting finding of this study is the mean difference in rotation between the TEA and the PCA. The TEA was 4.3° externally rotated from the PCA. Individual knees, however, showed considerable variability (range, 2.8°-6.1°). This may reflect a small amount of measurement error but more likely represents anatomical differences in our specimens. For instance, it is well established that, compared with white patients, Asian patients often have significant rotational differences in knee anatomy. Furthermore, using digitized radiographs to measure each knee allowed us to more precisely define our TEA and PCA than would be the case in the intraoperative setting.

It is noteworthy that, though we attempted to achieve correct rotation in half our specimens, there was a tendency toward internal rather than external rotation. This observation lends further support to the notion that using only one marker of rotation, such as 3° of external rotation from the PCA, may underestimate where the TEA truly exists.

Surgeons who perform TKAs should be comfortable using all the femoral axes, including the TEA, the PCA, and the AP axis. Unfortunately, these may not be easily identifiable or readily accessible in all knees. This may be most apparent when there is difficult or limited visualization, such as is the case with a patient with a large body habitus or during minimally invasive surgery. Furthermore, valgus deformity leads to reduced reliability of the TEA, the PCA, or the AP axis in terms of obtaining a symmetric flexion gap.[1]

A limitation of this study was its small sample size. Four specimens were lost because of anterior notching. However, the other 14 specimens were enough to show a statistically significant association between M:L ratios and rotation as judged by both the TEA and the PCA. Furthermore, our regression analysis revealed a strong correlation between these measures ($r = .082$).

Another consideration is that femoral rotation is one of several factors that could potentially influence the appearance of the grand piano sign. In an earlier experiment performed using saw bone models, we found that excessive translation of our cutting block led to differing shapes on the anterior femur (T. F. M. and A. U., unpublished data, 2003).

In addition, incorrect component sizing also can affect the shape of the grand piano sign. In this study, we were very careful to appropriately size our specimens, and we were vigilant about placement of the femoral cutting block. Nevertheless, it must be emphasized that errors (other than malrotation) encountered during TKA could lead to an absence of the grand piano sign, notching of the anterior femur, or both.

For example, undersizing or oversizing the femoral component, as well as incorrectly cutting the distal femur in excessive flexion or extension, could reduce the reliability of the grand piano sign. Therefore, when an unexpected result occurs after the anterior femoral osteotomy is performed, the surgeon must assess for several common technical errors, including malrotation, incorrect sizing, and inaccurate placement of the cutting block in both the AP and flexion-extension planes.

We emphasize that the grand piano sign is not meant to replace previous methods of evaluating femoral alignment. In addition, we do not believe that the grand piano sign by itself is necessarily more accurate than the TEA, the PCA, or the AP axis. Rather, it is an additional tool for assessing correct rotation of the femur during TKA. When the anterior femur has a bimodal peak approximately 2 times higher on the lateral side than on the medial side, the surgeon likely has avoided significant or substantial malrotation of the femoral osteotomy. Of course, this depends on accurate placement of the femoral cutting block and correct sizing of the component. With these parameters in mind, surgeons who are knowledgeable about the grand piano sign should find it helpful when orienting components during knee replacement surgery.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

References

1. Olcott CW, Scott RD. Femoral component rotation during total knee arthroplasty. *Clin Orthop.* 1999;(367):39-42.
2. Pollice P, Lotke PA, Lonner JH. Principles of instrumentation and component alignment. In: Callaghan JJ, Rosenberg AG, Rubash HE, Simonian PT, Wickiewicz TL, eds. *The Adult Knee.* Philadelphia, PA: Lippincott Williams & Wilkins; 2003:1091-1092.
3. Armstrong AD, Brien HJ, Dunning CE, King GJ, Johnson JA, Chess DG. Patellar position after total knee arthroplasty: influence of femoral component malposition. *J Arthroplasty.* 2003;18(4):458-465.
4. Scuderi GR, Insall JN, Scott NW. Patellofemoral pain after total knee arthroplasty. *J Am Acad Orthop Surg.* 1994;2(5):239-246.
5. Lee GC, Cushner FD, Scuderi GR, Insall JN. Optimizing patellofemoral tracking during total knee arthroplasty. *J Knee Surg.* 2004;17(3):144-149.
6. Barrack RL, Schrader T, Bertot AJ, Wolfe MW, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. *Clin Orthop.* 2001;(392):46-55.
7. Jenny JY, Boeri C. Low reproducibility of the intra-operative measurement of the transepicondylar axis during total knee replacement. *Acta Orthop Scand.* 2004;75(1):74-77.
8. Jerosch J, Peuker E, Philipps B, Filler T. Interindividual reproducibility in perioperative rotational alignment of femoral components in knee prosthetic surgery using the transepicondylar axis. *J Knee Surg Traumatol Arthrosc.* 2002;10(3):194-197.
9. Eckhoff DG, Metzger RG, Vandewalle MW. Malrotation associated with implant alignment technique in total knee arthroplasty. *Clin Orthop.* 1995;(321):28-31.
10. Luo CF. Reference axes for reconstruction of the knee. *Knee.* 2004;11(4):251-257.
11. Katz MA, Beck TD, Silber JS, Seldes RM, Lotke PA. Determining femoral rotational alignment in total knee arthroplasty: reliability of techniques. *J Arthroplasty.* 2001;16(3):301-305.