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Basic Science

# Does Kinematic Alignment and Flexion of a Femoral Component Designed for Mechanical Alignment Reduce the Proximal and Lateral Reach of the Trochlea?

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ABSTRACT

*Background:* Kinematically aligned total knee arthroplasty uses a femoral component designed for mechanical alignment (MA) and sets the component in more internal, valgus, and flexion rotation than MA. It is unknown how much kinematic alignment (KA) and flexion of the femoral component reduce the proximal and lateral reach of the trochlea; two reductions that could increase the risk of abnormal patella tracking.

*Methods:* We simulated MA and KA of the femoral component in 0° of flexion on 20 3-dimensional bone models of normal femurs. The mechanically and kinematically aligned components were then aligned in 5°, 10°, and 15° of flexion and downsized until the flange contacted the anterior femur. The reductions in the proximal and lateral reach from the proximal point of the trochlea of the MA component set in 0° of flexion were computed.

*Results:* KA at 0° of flexion did not reduce the proximal reach and reduced the lateral reach an average of 3 mm. Flexion of the MA and KA femoral component 5°, 10°, and 15° reduced the proximal reach an average of 4 mm, 8 mm, and 12 mm, respectively (0.8 mm/degree of flexion), and reduced the lateral reach an average of 1 mm and 4 mm regardless of the degree of flexion, respectively.

*Conclusion:* Arthroplasty surgeons and biomechanical engineers striving to optimize patella tracking might consider developing surgical techniques to minimize flexion of the femoral component when performing KA and MA total knee arthroplasty to promote early patella engagement and consider designing a femoral component with a trochlea shaped specifically for KA.



Patella-femoral complications are a common cause of patient dissatisfaction and a reason for revision after mechanically aligned total knee arthroplasty (TKA) [1,2]. These complications include anterior knee pain, patellar crepitus, and less frequently patellar subluxation, dislocation, and fracture [2-4]. The intended settings of a femoral component designed for mechanical alignment (MA) are in 3° to 5° of external rotation relative to the posterior condylar axis or the transepicondylar axis and perpendicular to the coronal mechanical axis of the femur, which is a line that connects the center of the femoral head and the center of the distal femur at the apex of the intercondylar notch [5,6] (Fig. 1). When the femoral component is too wide and the anterior-posterior fit is acceptable, flexion from 0° is used to downsize the femoral component to a narrower width and to assist in balancing the flexion gap [7]. Femoral components designed for MA strive to maximize the proximal and lateral reach of the trochlea to promote early patella engagement, more normal patellar tracking, and even the distribution of contact stress on the patellar [8-13].

A level 1 randomized trial reported use of a kinematic alignment technique provided better pain relief and restored better function and range of movement than the MA technique, and a national

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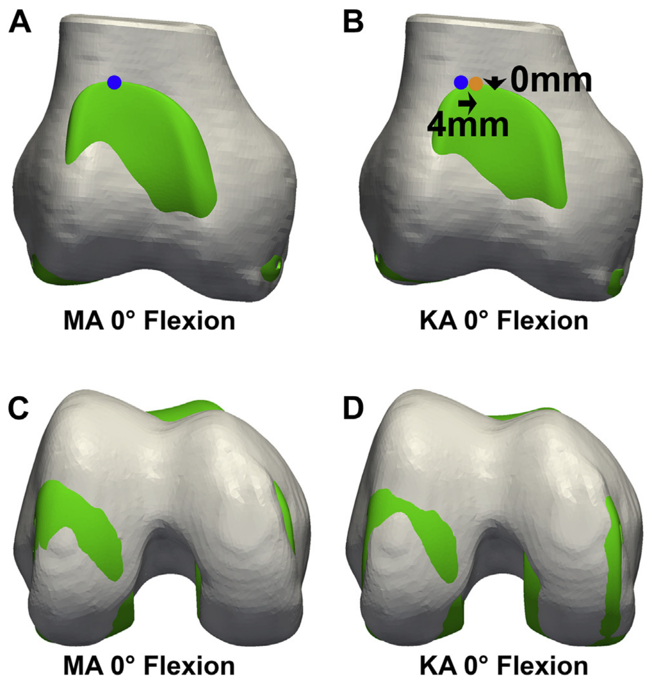


**Fig. 1.** The composite of a representative right distal femur shows the coronal (A and B) and axial (C and D) views and the position of the mechanically aligned and kinematically aligned femoral component designed for MA set at 0° of flexion. The reductions in proximal reach (arrow pointing distal) and lateral reach (arrow pointing medial) from the proximal point of the trochlea of the mechanically aligned component (blue dot) are shown for the kinematically aligned component (orange dot). KA set the femoral component in more valgus and internal rotation than MA, which did not reduce the proximal reach of the trochlea and reduced the lateral reach 4 mm. MA, mechanical alignment; KA, kinematic alignment.

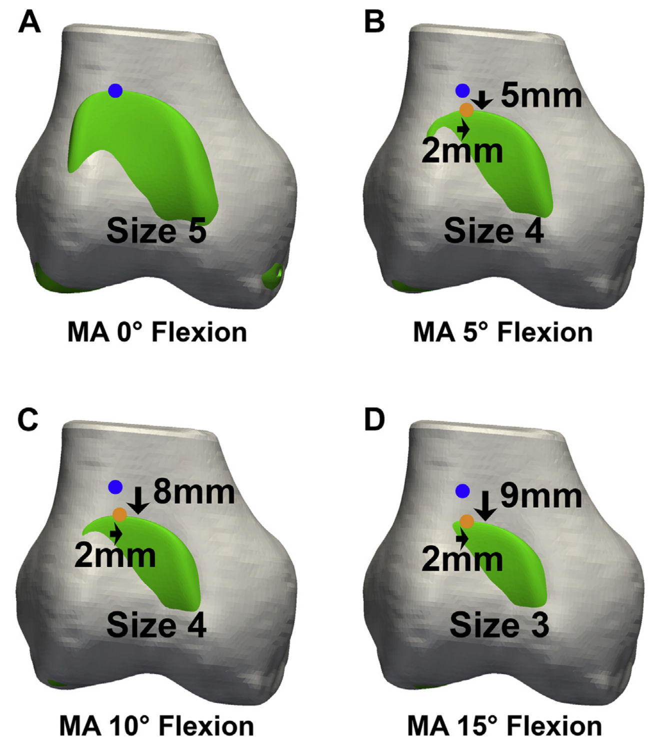


**Fig. 2.** The composite shows a representative right distal femur and the 2 mm (B), 8 mm (C) and 9 mm (D) reductions in proximal reach (arrows pointing distal), lateral reach (arrows pointing medial), and the 1 (B), 1 (C), and 2 (D) reductions in femoral component size from flexing the mechanically aligned femoral component from 0° (A) to 5° (B), 10° (C), and 15° (D) of flexion.

multicenter study showed a trend toward more patients treated with kinematically aligned TKA reporting their knee to feel "normal" when compared with a mechanically aligned TKA [14,15]. Kinematic alignment uses a femoral component designed for MA and sets the component in an average of 5° more flexion, 2° more valgus rotation, and 3° less external rotation than that the position of the femoral component set by MA [14]. Although both treatment groups in the randomized trial had the same 4.5% incidence of patella-related complications requiring additional surgery in the first 2 years, there is a concern that kinematic alignment of the femoral component delays the capture of the patella by the trochlear groove during early knee flexion and increases the risk of patellar-femoral instability [16].

The purpose of the present study was to use kinematic alignment and MA to set a femoral component designed for MA in 0°, 5°, 10°, and 15° of flexion on 20 3-dimensional bone models of normal femurs. We tested the hypothesis that kinematic alignment and flexion of a mechanically and a kinematically aligned femoral component cause a reduction in the proximal and lateral reach of the trochlea and the size of the femoral component, which is of interest to those arthroplasty surgeons and biomechanical engineers striving to optimize patella tracking.

## Methods

After receiving approval from our institutional review board to access our prospective database, we reviewed axial computer tomograms of the femoral head, knee, and ankle, and an anterior-posterior and lateral scanogram of both limbs obtained on the day of discharge of 491 consecutive patients who were treated with a primary TKA between August 2013 and September 2014. We randomly selected femurs from 20 subjects who were characterized as normal based on the following inclusion criteria: (1) a review of the history and physical reported that the contralateral knee and limb were normal without prior surgery, (2) the computer tomogram and scanogram of the contralateral knee and limb showed a normal patella-femoral joint with no patella subluxation and no evidence of arthritis, fracture, internal fixation, or a joint arthroplasty, and (3) the reconstruction of a 3-dimensional femoral bone model from the computer tomogram of the contralateral knee and limb showed a complete femoral head and distal femur. The femoral head, knee, and distal tibial plafond of the 3-dimensional bone models were shape fit to the 2-dimensional projection of the anterior-posterior scanogram to create a model of the limb (ParaView, version 4.3.1, 64 bit; Kitware, Clifton Park, NY).

The following steps describe the simulation for setting the femoral component designed for MA (Vanguard Cruciate-Retaining; Biomet, Inc, Warsaw, IN) with MA and with kinematic alignment on each femoral bone model. For this implant design, the anterior-posterior height increased 2.2 mm and the medial-lateral width increased 2.4 mm with each increase in component size. The design of this femoral component accommodates a range from 7° flexion to 4° extension relative to the sagittal MA of the femur. MA set the medial-lateral axis of the femoral component designed for MA perpendicular to the coronal mechanical axis of the femur, which was a line connecting the center of the femoral head and the center of the distal femur at the apex of the intercondylar notch [5]. The minimum thickness of the bone resection from the distal region of a femoral condyle was 7 mm, which equaled the 9-mm thickness of the corresponding region of the femoral component condyle after accounting for a mean articular cartilage thickness of

2 mm [17]. The anterior-posterior axis of the femoral component was set perpendicular to a line rotated 3° externally from the posterior condylar axis of the femur. The posterior articular surface of the femoral component was positioned 9 mm anterior to the most posterior point of the lateral femoral condyle. The flexion of the femoral component was set at 0°, which was parallel to the sagittal mechanical axis of the femur as defined by a line connecting the center of the femoral head and the center of the distal femur at the apex of the intercondylar notch. The size of the femoral component was reduced, when necessary, until the flange of the femoral component contacted the anterior femur without notching.

For the osteoarthritic knee treated with a kinematically aligned TKA, the reported mean and standard deviation of internal-external rotation of the anterior-posterior axis femoral component from the flexion-extension plane of the knee is 0° ± 1°, and the varus-valgus range of the femoral component from the coronal mechanical axis of the femur is −1° valgus ± 2° [14,18]. We were unable to find any studies that reported the mean and standard deviation of the flexion-extension of the femoral component from the sagittal mechanical axis of the femur. Kinematic alignment sets the femoral component designed for MA tangential to the distal and posterior joint lines of the femur. Flexion was set at 0°, which was parallel to the sagittal mechanical axis of the femur. The mechanically aligned and kinematically aligned femoral components were then flexed 5°, 10°, and 15°, and the size of the femoral component was reduced, when necessary, until the flange of the femoral component contacted the anterior femur without notching.

The following steps computed the reduction in proximal and lateral reach of the trochlea. The reference was the proximal point of the trochlea of the mechanically aligned femoral component set in 0° of flexion. The reductions in the proximal and lateral reach caused by kinematic alignment and caused by flexion of the kinematically aligned and the mechanically aligned femoral component designed for MA were the changes in the distal direction and medial direction, respectively, of the proximal point of the trochlea (Figs. 1-3).

### Statistical Analyses

To quantify reproducibility, 2 observers independently computed the reductions in proximal and lateral reach and reductions in femoral component size caused by kinematic alignment and caused by flexion of the kinematically aligned and the mechanically aligned femoral component on 10 randomly selected bone models. The intraclass correlation coefficient (ICC) was computed for the reductions in proximal and lateral reach and reductions in femoral component size for each method of aligning the femoral component. For each measurement, a 2-factor analysis of variance (ANOVA) with mixed effects was used to compute the ICC. The first factor had 2 levels (observer 1 and observer 2) and was the fixed effect. The second factor had 40 levels (bone models 1-10, flexion angles 0°, 5°, 10°, and 15°) and was the random effect. An ICC value of >0.9 indicates excellent agreement, 0.75-0.90 indicates good agreement, and 0.5-0.75 indicates moderate agreement [19]. The ICC ranged from 0.96 to 0.97 for the reduction in proximal reach, 0.74-0.78 for the reduction in lateral reach, and 0.73-0.78 for the reduction in component size for each method of aligning the femoral component.

Software (JMP, version 11.2.0, 64 bit; SAS Inc, Cary, NC, www.jmp.com) computed the average, standard deviation, and the following statistical tests. A 1-tailed Student $t$ tests determined whether kinematic alignment of the femoral component set at 0° reduced the proximal and lateral reach from the MA of the femoral component set at 0°. One-factor repeated measures

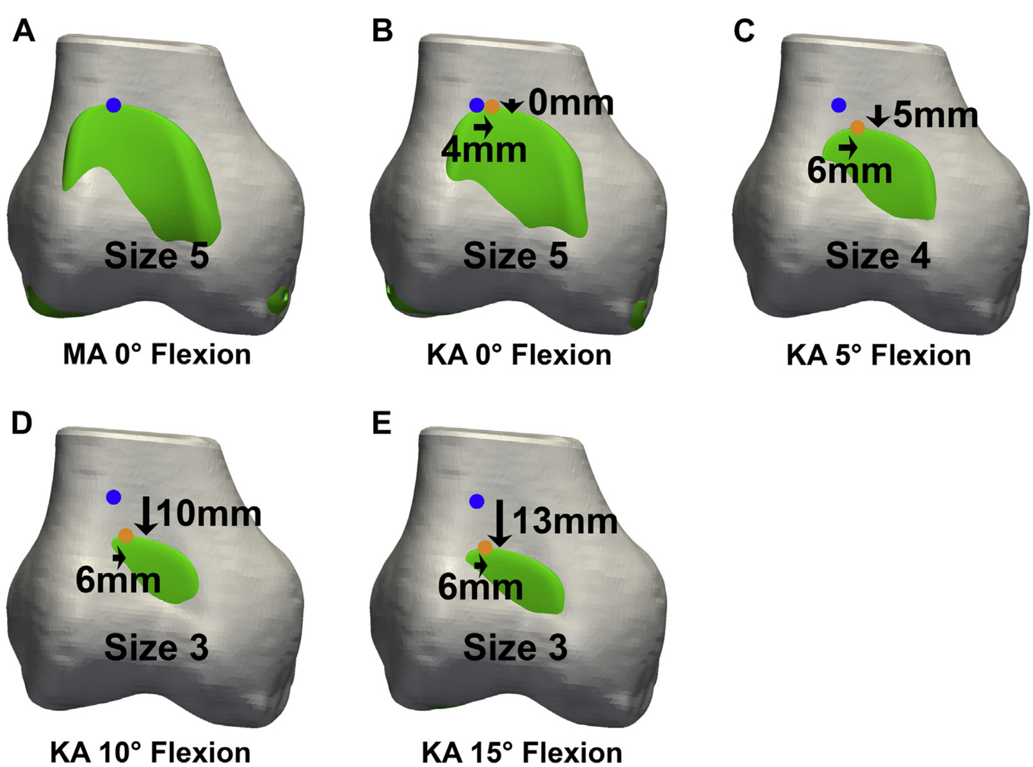


**Fig. 3.** The composite (A) shows a representative model of a normal right distal femur and the 5 mm (C), 19 mm (D) and 13 mm (E) reductions in proximal reach (arrows pointing distal), the 2 mm (C), 2 mm (D) and 2 mm (E) in the lateral reach (arrows pointing medial), and the 1 (C), 1 (D), and 2 (E) reductions in femoral component size from flexing the kinematically aligned femoral component from 0° (B) to 5° (C), 10° (D), and 15° (E) of flexion.

ANOVAs determined whether 5°, 10°, and 15° of flexion of the mechanically aligned and kinematically aligned femoral components from 0° of flexion reduced the proximal and lateral reach, and a Tukey's test determined the flexion angles associated with a significant reduction in the proximal reach and lateral reach. Another 1-factor repeated measures ANOVA determined whether 5°, 10°, and 15° of flexion of the mechanically aligned and kinematically aligned femoral components from 0° of flexion reduced the size of the femoral component, and a Tukey's test determined the flexion angles associated with a significant reduction in component size. Significance was set at $P < .05$.

## Results

Setting the femoral component designed for MA with kinematic alignment did not reduce the proximal reach, which averaged 0 ± 1 mm ($P = .309$; Fig. 4), and did reduce the lateral reach, which averaged 3 ± 1 mm ($P < .0001$; Fig. 5) when compared to the femoral component set with MA.

Flexion of the mechanically aligned and kinematically aligned femoral component significantly reduced the proximal reach ($P < .0001$ and $P < .0001$, respectively; Fig. 4). On average, flexion of the mechanically aligned and the kinematically aligned femoral components reduced the proximal reach by 4 ± 1 mm and 5 ± 1 mm at 5° of flexion ($P < .0001$ and $P < .0001$), 8 ± 1 mm and 9 ± 1 mm at 10° of flexion ($P < .0001$ and $P < .0001$), and 12 ± 2 mm and 13 ± 1 mm at 15° of flexion ($P < .0001$ and $P < .0001$), respectively.

Flexion of the mechanically aligned and kinematically aligned femoral components significantly reduced the lateral reach ($P = .0002$ and $P < .0001$, respectively; Fig. 5). On average, flexion of the mechanically aligned femoral component did not reduce the lateral reach at 5° of flexion (1 ± 1 mm, $P = .144$) but did reduce the lateral reach by 1 ± 1 mm at 10° and 15° of flexion ($P = .019$ and $P < .0001$, respectively). On average, flexion of the kinematically aligned femoral component reduced the lateral reach by 4 ± 1 mm at 5° of flexion ($P = .001$) and by 5 ± 2 mm at 10° and 15° of flexion ($P < .0001$ and $P < .0001$, respectively).

Flexing the femoral component 5°, 10°, and 15° from 0° with kinematic and MA reduced its size by 0.8 ± 0 and 0.6 ± 1 at 5° of flexion ($P < .0001$ and $P < .0001$), 1.5 ± 1 and 1.2 ± 0 at 10° of flexion ($P < .0001$ and $P < .0001$), and 2.1 ± 0 and 1.7 ± 0 at 15° of flexion ($P < .0001$ and $P < .0001$), respectively (Fig. 6).

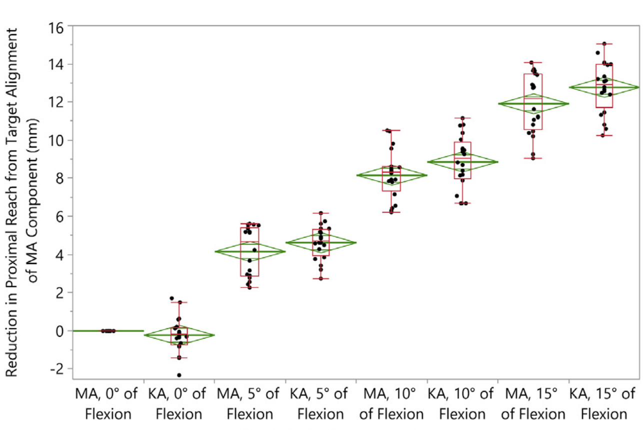


**Fig. 4.** The graph displays the diamond (green), which illustrates the mean and 95% confidence interval, and an outlier quartile box plot (red), which shows the variability in the reduction in proximal reach from the proximal point of the mechanically aligned femoral component set at 0° of flexion from flexing the mechanically aligned and kinematically aligned femoral components 5°, 10°, and 15°.

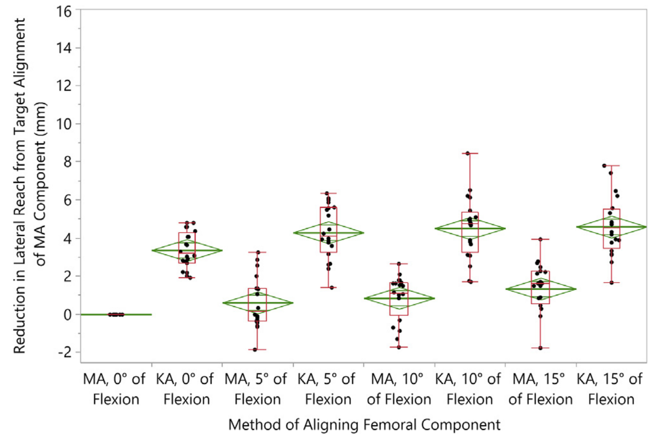


**Fig. 5.** The graph displays the diamond (green), which illustrates the mean and 95% confidence interval, and an outlier quartile box plot (red), which shows the variability in the reduction in lateral reach from the proximal point of the mechanically aligned femoral component set at 0° of flexion from flexing the mechanically aligned and kinematically aligned femoral components 5°, 10°, and 15°.

## Discussion

Femoral components designed for MA strive to maximize the proximal and lateral reach of the trochlea to promote early patella engagement, more normal patellar tracking, and even the distribution of contact stress on the patellar [8-13]. Because 1 study showed that kinematic alignment sets the femoral component in an average of 5° more flexion, 2° more valgus rotation, and 3° less external rotation than MA, and because flexion of the femoral component is used to downsize the femoral component, the present study determined the reductions in proximal and lateral reach from setting the femoral component with kinematic alignment and from flexing the femoral component with kinematic and MA. The most important findings of the present study were that (1) kinematic alignment of the femoral component did not reduce the proximal reach but reduced the lateral reach by 3 mm, (2) flexion of

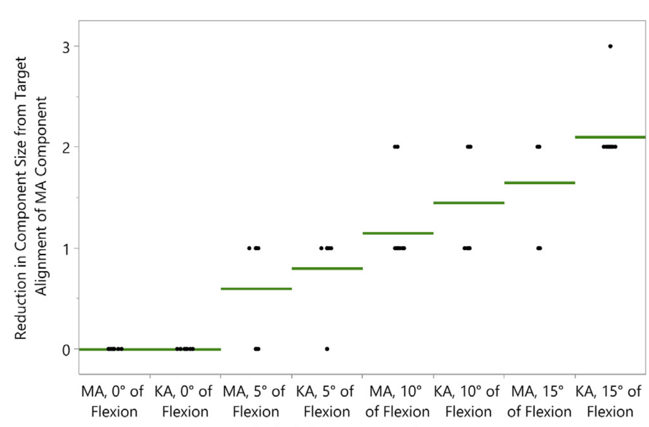


**Fig. 6.** The composite shows the mean (green) for the reduction in component size from the target alignment of the mechanically aligned femoral component for the mechanically aligned and kinematically aligned femoral components in 0°, 5°, 10°, and 15° of flexion. Flexing the mechanically aligned and kinematically aligned femoral components from 0° to 5° reduced the component size by 1 size in 60% and 80% of cases, respectively. Flexing the mechanically aligned and kinematically aligned femoral components from 0° to 10° reduced the component size by 1 size in 85% and 55% of cases and by 2 sizes in 15% and 45% of cases, respectively. Flexing the mechanically aligned and kinematically aligned femoral components from 0° to 15° reduced the component size by 1 size in 35% and 0% of cases, by 2 sizes in 65% and 90% of cases, and by 3 sizes in 0% and 10 % of cases, respectively.

the femoral component set with mechanical and kinematic alignments reduced the proximal reach by an average of approximately 0.8 mm/degree of flexion, (3) flexion reduced the lateral reach by an average of 1 mm and 4 mm when set with mechanical and kinematical alignments, respectively, and (4) the size of the femoral component was reduced by 0.6 of a size/5° flexion and 0.8 of a size/5° flexion when set with mechanical and kinematic alignments, respectively.

Before interpreting the results, 1 limitation should be discussed. The present study evaluated only 1 femoral component design and used a specific reference point on the trochlea to determine the reduction in the proximal and lateral reach of the trochlea and size of the femoral component. Other femoral component designs do have different shaped trochlea and different dimensional changes between sizes of the femoral component than the femoral component used in the present study. Analysis of femoral components with a different design from the femoral component in the present study might yield different reductions in the proximal and lateral reach. The selection of a specific reference point can affect the measurement of the reduction in proximal and lateral reach. The use of the most proximal point of the trochlea as the reference in the present study produces the greatest reductions in proximal and lateral reach when the femoral component is realigned in flexion or valgus rotation because this point is further from the axis of rotation than a more distal point. Although the use of a different femoral component design and more distal reference point on the trochlea could result in a difference in the magnitude of the reductions in proximal and lateral reach from those reported in the present study, the patterns of the reductions in proximal and lateral reach would be similar to those of the present study.

The reduction in the lateral reach caused by kinematic alignment of femoral component designed for MA suggests that there is a need to design a femoral component with the shape of the trochlea optimized for kinematic alignment. Current femoral components designed for MA set the femoral component in more external rotation and varus rotation than when set with kinematic alignment [14]. The present study found that changing the alignment of the femoral component from mechanical to kinematic alignment reduced the lateral reach of the trochlea by 3 mm, which may be of some clinical importance. A study of 14 femoral components different from the one used in the present study showed that for each degree of internal rotation of the trochlear groove, the lateral reach is reduced approximately 0.5 mm, which for 3° of less external rotation is half the 3 mm reduction in lateral reach reported in the present study [20]. Internal rotation has been associated with abnormal patellar tracking and an uneven distribution of contact stress on the patellar component [9]. However, a randomized clinical trial reported the same 4.5% incidence of patella-related complications for mechanically and kinematically aligned TKA, and this suggests that a 3-mm reduction in lateral reach might not be clinically important.

Consideration should be given to developing surgical techniques and designing femoral components that minimize or compensate for the reduction in the proximal reach caused by flexion of the kinematically and mechanically aligned femoral component. The reduction in the proximal reach caused by flexion of the kinematic and MA of the femoral component suggest that consideration should be given to adopting surgical techniques and providing femoral components with enough sizes to minimize the need to flex the femoral component. The present study showed that flexing the mechanically aligned and kinematically aligned femoral components by 10° reduced the proximal reach of the trochlea by approximately 9 mm. Controlling the anterior-posterior placement of the entry hole for an intramedullary rod attached to a distal cutting guide can minimize flexion of the femoral component. A more posterior entry hole is associated with a mean of 9° of flexion and a more anterior entry hole is associated with a mean of 2° of recurvatum of the femoral component with respect to the sagittal mechanical axis of the femur [21] (Fig. 7).

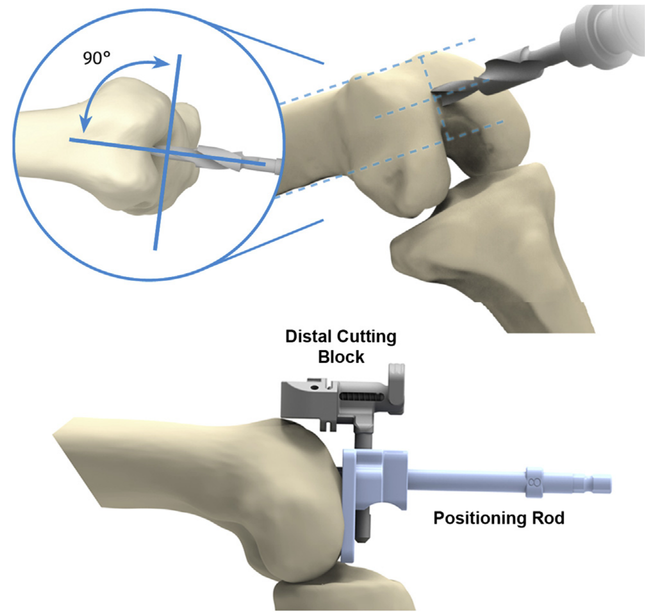


**Fig. 7.** The composite shows the method of setting the flexion of the femoral component with KA with use of a distal cutting block attached to a positioning rod that is inserted 8-10 cm through a central entry point midway between the apex of the notch and the anterior femoral cortex proximal to the trochlea and aligned parallel to the anterior femoral shaft and perpendicular to the distal femoral joint line.

Although flexion of the femoral component has been used as a method to downsize the femoral component and balance the flexion gap [7], the present study has shown that it also causes a reduction in the proximal and lateral reach of the trochlea. There are 2 mechanisms responsible for these 2 reductions. First, flexion of the femoral component reduces the proximal reach of the trochlea by moving the trochlea distally on the femur. Second, when flexion of the femoral component forces a downsizing of the femoral component, there is a reduction in the proximal-distal and medial-lateral dimensions of the anterior flange that reduces the proximal and lateral reach.

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