Effect of Tibial Slope on Coronal Alignment in Total Knee Arthroplasty

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Abstract

Malalignment of total knee arthroplasty (TKA) components affects function and survivorship. Common practice is to set coronal alignment prior to adjusting slope. With improper jig placement, adjustment of the slope may alter coronal alignment. The purpose of this study was to quantify the change in coronal alignment with increasing posterior tibial slope while comparing two methods of jig fixation. Prospective consecutive series of 100 patients underwent TKA using computer navigation. Fifty patients had extramedullary cutting jig secured proximally with one pin and 50 patients had jig secured proximally with two pins. Coronal alignment (CA) was recorded with each increasing degree of posterior slope (PS) from 0 to 7 degrees. Mean CA and change in CA were compared between cohorts. Utilizing one pin, osteotomies drifted into varus with an average change in CA of 0.34 degrees per degree PS. At 4 degrees PS, patients started to have >3 degrees of varus with 12.0% having >3 degrees of varus at 7 degrees PS. Utilizing two pins, osteotomies drifted into valgus with an average change of 0.04 degrees in CA per degree PS. No patients in the two-pin cohort fell outside 3 degrees varus/valgus CA. CA was significantly different at all degrees of PS between the cohorts. Changes in PS influenced CA making verification of tibial cut intraoperative critical. Use of >1 pin and computer navigation were beneficial to prevent coronal plane malalignment. This relationship may explain why computer navigation has been shown to improve alignment as well as survivorship and outcomes in some patients, especially those <65 years.[Q4]

Keywords
- total knee arthroplasty
- computer navigation
- coronal alignment[Q5]

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Total knee arthroplasty (TKA) has become a highly successful operation when treating patients with end stage osteoarthritis. As the population of the United States continues to age, the number of projected TKA procedures performed annually continues to rise.[1] Malalignment in TKA may affect implant function and lead to decreased survival.[2–5] Computer navigation increases the precision and accuracy of component placement.[6–10] Until recently, there has been little evidence of improved survivorship, outcomes, and patient satisfaction in patients undergoing TKA utilizing computer navigation.[11–15] This is a possible explanation for the slow adaptation of computer navigation in TKA and why conventional TKA continues to be the most common technique utilized for TKA in the United States as well as most other countries around the world. Conventional TKA instruments rely on anatomical landmarks to guide with accurate placement of cutting jigs to allow for appropriate osteotomies to restore the desired

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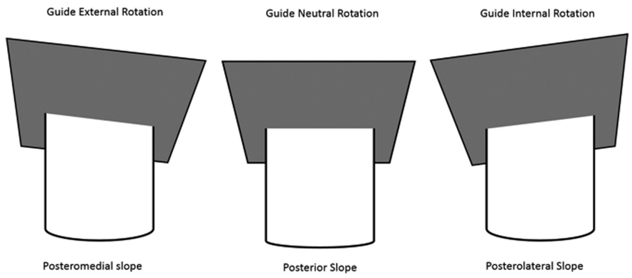

Fig. 1 Picture demonstrating the relationship between positioning of the extramedullary tibial cutting jig and changes in coronal alignment with increasing posterior slope.

limb alignment. Commonly, for the tibia, an extramedullary cutting guide is utilized.

For the tibial cut, the most commonly used proximal anatomical landmark to set rotational alignment is the junction of the medial and mid one-third of tibial tubercle. A common technique is to pin the proximal aspect of the guide in line with this landmark prior to making any adjustments to the coronal alignment or tibial slope. Adjustments can be made to these parameters prior to pinning, but attempting to adjust all the parameters (slope, coronal alignment, height, and rotation) prior to pinning the jig can be cumbersome. Surgeons may vary the number of pins used to secure the jig. One of our senior authors utilizes a single pin to secure the jig while the other uses two. The surgeon who utilizes one does so for efficiency and concern for increased risk of fracture with multiple pins as has previously been reported in the unicompartmental knee arthroplasty literature.[16]

Placement of the jig in line with this tibial tubercle landmark is essential. It has previously been described in the literature that if the jig is not appropriately aligned, cutting the tibia with any amount of slope will alter the coronal alignment.[17] For example, if the guide is externally rotated, the slope is cut in a posteromedial direction and it will cause increased varus in the cut in the coronal plane (►**Fig. 1**). This effect is magnified with increased slope. Typically, the coronal alignment is set first using an extramedullary guide and then the posterior slope is set.[17]

Increasing the amount of slope in the tibial cut increases the possible change in coronal alignment if the jig position changes. Different TKA designs recommend varying degrees of posterior slope in the tibial osteotomy for ideal implant function. Some cruciate retaining total knee designs recommend up to 7 degrees of posterior slope in the tibial osteotomy to maximize function.[18] If the jig is misaligned, this has the potential to significantly alter the desired coronal alignment of the osteotomy.

Computer navigation allows these alterations in the coronal alignment to be realized in real-time during the procedure as well as for further coronal plane adjustment so that the desired target coronal and sagittal alignment are obtained. The objectives of this study were to quantify the change in coronal alignment of an extramedullary tibial cutting jig as the posterior slope of the proximal tibial cut was increased and to evaluate how rigidity of fixation (one pin vs. two pins) in the proximal tibia may change the coronal alignment when the posterior slope was increased. The relationship between coronal alignment and tibial slope is important as it can have an impact on the final implant position and limb alignment. Deviating from the preoperative goal, whether that be restoring mechanical axis alignment or kinematic alignment of the knee, may influence the survivorship of the implant and the functional outcome for the patient.

Methods

This study is a prospective consecutive series of patients undergoing TKA performed by two surgeons at a large academic hospital. Prior to initiating the study, IRB approval was obtained (IRB-19–312) by our institutions IRB on December[Q6] 4, 2019. Patients identified as potential study participants were consecutive patients scheduled to undergo TKA utilizing computer navigation with two surgeons. There were no exclusion criteria. These patients were provided with a detailed description of the risks, benefits, and alternatives of participating in the study and gave signed informed consent during their preoperative clinic visit. Q6

Operative Technique

All patients underwent a standard midline incision with medial parapatellar approach and placement of computer navigation arrays. The same computer navigation system was utilized by both surgeons. At the time of the tibial cut, the extramedullary cutting guide was clamped to the ankle distally and then navigated into position. The first cohort of 50 patients treated by a single surgeon had the cutting jig held in place with one pin into the proximal tibia after the desired resection level and rotation were obtained. The second cohort of 50 patients treated by a second single surgeon had the guide held in place with two pins in the proximal tibia after the desired resection level and rotations were obtained. The jig was initially set at 0 degrees varus/valgus and 0 degrees posterior slope in both cohorts. The posterior slope was sequentially increased in 1 degree increments from 0 to 7 degrees and the coronal alignment was recorded with each degree of change. Jig position was then return to planned resection position for each surgeon and the tibial cut was performed. The navigation verification tool was utilized to record the final tibial cut alignment. The remainder of the procedure was performed per the surgeon's usual technique.

Statistical Analysis

Independent statistical analysis was performed. A power analysis was performed which returned a sample size of 64 patients with cohorts of 32 patients each necessary to make our study results valid. Mean coronal alignment was calculated for each cohort at each degree of posterior slope. Also, the mean change in coronal alignment per change in degree of posterior slope was calculated for each cohort. Finally, the mean final tibial cut alignment was calculated for each cohort and compared with the surgeon target. These data were evaluated and felt to be appropriate for pooled *t*-test and ANOVA. Coronal alignment was compared between the two groups at each recorded degree of posterior slope.

Results

There were statistically significant differences between the mean coronal alignment in each cohort with each degree of increasing posterior slope (►**Table 1**) with *p*-values of <0.0001 for each degree of posterior slope. All the tibial osteotomies drifted into increased varus in the single pin cohort. The mean coronal alignment at 7 degrees posterior slope for the single pin cohort was 2.38 degrees varus with a range of 0.5 to 4.5 degrees varus. The tibial osteotomies in the two-pin cohort had a propensity to drift into valgus to a less significant degree. The mean coronal alignment at 7 degrees posterior slope for the two-pin cohort was 0.22 degrees valgus with a range of 1 degree varus to 1.5 degrees valgus. Six of the 50 patients in the single pin cohort (12.0%) had >3 degrees of varus at 7 degrees posterior slope while there were zero patients in the two-pin cohort who had >1.5 degrees valgus at 7 degrees posterior slope. The mean change in coronal alignment per degree of increased posterior slope in the single pin cohort was 0.34 degrees while the average change in the two-pin group was 0.04 degrees (►**Table 2**).

The mean final tibial cut alignment in the single pin group was 0 degrees varus/valgus and 2.04 degrees posterior slope while the surgeon target was 0 degrees varus/valgus with 2 degrees posterior slope. The mean final tibial cut alignment in the two-pin group was 0 degrees varus/valgus with 0.88 degrees posterior slope while the surgeon target was 0 degrees varus valgus with 0 degrees posterior slope. There were no tibial fractures identified in either group.

Discussion

Our study demonstrates that changes in tibial slope do influence coronal alignment. It also demonstrated that the use of one pin resulted in an increased deviation from desired coronal alignment with increasing amounts of posterior slope when compared with two pins. One possible explanation for this observation is that the jig may be able to rotate around the single pin despite distal stabilization provided by ankle clamp portion of the extramedullary guide as the slope is increased resulting in changes in the coronal alignment while the second pin provides more constraint and does not allow for as much rotation.

It was also observed in this study that computer navigation helps surgeons achieve their preoperative tibial osteotomy target more precisely as it allows them to identify in real

Table 1 Mean coronal[Q7] alignment at increasing degrees of posterior slope

Q7

	Single pin		Two pin		*p*-Value
Posterior slope	Mean coronal alignment	Range	Mean coronal alignment	Range	
1 degree	0.26 degrees Varus	0.0–0.5 degrees Varus	0.01 degrees Valgus	0.5 degrees Valgus–0.5 degrees Varus	<0.0001
2 degrees	0.63 degrees Varus	0.0–1.5 degrees Varus	0.09 degrees Valgus	0.5 degrees Valgus–1.0 degrees Varus	<0.0001
3 degrees	1.01 degrees Varus	0.0–2.5 degrees Varus	0.05 degrees Valgus	1.0 degrees Valgus–0.5 degrees Varus	<0.0001
4 degrees	1.35 degrees Varus	0.0–2.5 degrees Varus	0.12 degrees Valgus	1.5 degrees Valgus–1.0 degrees Varus	<0.0001
5 degrees	1.75 degrees Varus	0.5–3.5 degrees Varus	0.16 degrees Valgus	1.5 degrees Valgus–1.0 degrees Varus	<0.0001
6 degrees	2.06 degrees Varus	0.5–4.0 degrees Varus	0.20 degrees Valgus	1.5 degrees Valgus–1.0 degrees Varus	<0.0001
7 degrees	2.38 degrees Varus	0.5 degrees –4.5 degrees Varus	0.22 degrees Valgus	1.5 degrees Valgus–1.0 degrees Varus	<0.0001

Table 2 Mean change in coronal alignment per degree of increased posterior slope

	Single pin		Two pin	
Posterior slope	Mean change Coronal alignment	Range	Mean change Coronal alignment	Range
0–1 degrees	0.26 degrees	0.0–0.5 degrees	0.01 degrees	0.0–0.5 degrees
1–2 degrees	0.37 degrees	0.0–1.0 degrees	0.08 degrees	0.0–0.5 degrees
2–3 degrees	0.38 degrees	0.0–1.5 degrees	0.04 degrees	0.0–0.5 degrees
3–4 degrees	0.34 degrees	0.0–1.5 degrees	0.07 degrees	0.0–0.5 degrees
4–5 degrees	0.40 degrees	0.0–1.0 degrees	0.04 degrees	0.0–1.0 degrees
5–6 degrees	0.31 degrees	0.0–1.0 degrees	0.04 degrees	0.0–1.0 degrees
6–7 degrees	0.31 degrees	0.0–1.0 degrees	0.02 degrees	0.0–0.5 degrees
Mean change	0.34 degrees		0.04 degrees	

time any changes in coronal alignment and correct them prior to performing the osteotomy. In our study, both surgeons strived for neutral mechanical axis restoration. Our data demonstrate that computer navigation allowed both to meet their preoperative planned osteotomies as demonstrated in our data with the final tibial cut alignment validation data. Un-noticed changes in coronal alignment using a conventional technique can lead to deviation from this preoperative target. Care should be taken when manually aligning the tibial cutting jig to recheck the coronal alignment if the slope of the jig has been altered prior to tibial osteotomy. Alternatively, jig malposition due to the interplay between coronal alignment and tibial may be avoided by setting the tibial slope prior to setting the coronal alignment. Therefore, we suggest that setting tibial slope prior to coronal alignment may be a preferred sequence of events.

This observed deviation from planned coronal alignment with increasing tibial slope, especially greater than 4 degrees, can have long-term consequences on implant survivorship and patient outcomes regardless of initial desired target. For example, in our study, with the goal of neutral mechanical axis restoration, six of 50 patients (12.0%) in the one pin cohort had a final coronal alignment of >3 degrees of varus at 7 degrees posterior slope. Multiple studies have reported that the goal of mechanical axis restoration should be within ± 3 degrees of neutral to maximize survivorship and outcome.[2,3,19] While computer navigation helps ensure alignment falls within that designated zone, until recently, it had not been shown that there is a significant difference in survivorship and outcomes using computer navigation.[11–15] There is emerging literature with longer term follow-up that demonstrate superior survivorship and outcomes in patients undergoing TKA utilizing computer navigation especially in patients younger than 65.[11,13,14] Additionally, Berend et al has previously reported a statistically increased rate of failure of the tibial component if positioned >3.9 degrees varus. In our one pin cohort, four of 50 patients (8.0%) would have been at risk for that increased rate of failure.[5] This concept can be extrapolated to the potential impact of coronal alignment deviation on the outcomes and survivorship of kinematically aligned knees. Therefore, careful consideration should be taken when utilizing conventional instrumentation and an implant system recommending large amounts of posterior slope.

Our data also demonstrates that as computer navigation and other enabling technologies continue to evolve, using less than two pins for proximal tibial jig fixation despite distal stabilization significantly increases the risk of malpositioning if it goes undetected. A malpositioned jig leads to alteration of the desired tibial cut which further underscores the importance of cut verification when utilizing these technologies in addition to the implications previously discussed for use of conventional instrumentation for TKA.

Our study is not without limitations. The use of one or two pins was not randomized between surgeons. Fifty consecutive patients were obtained using one pin by one surgeon and the second 50 consecutive patients were obtained using two pins by the second surgeon. While surgical technique was similar between the two surgeons, their final goal for tibial osteotomy differed with the first surgeon planning for 2 degrees posterior slope and the second surgeon planning for 0 degrees posterior slope. Also, each surgeon used a different extramedullary tibial cutting jig. The design is similar but each surgeon used a different implant system and thus a different tibial jig which we feel makes the potential for the guide to be a confounding factor minimal especially since in both groups we observed that changes in posterior slope resulted in changes in coronal alignment.

Conclusion

Based on these findings, when posterior slope is increased using an extramedullary cutting jig there is a propensity to alter the previously set coronal alignment of the jig. In our study, when one pin is utilized, increased slope resulted in varus alignment >3 degrees in six of 50 patients (12.0%) at 7 degrees posterior slope while zero patients in the two-pin cohort had a change in coronal alignment >1.5 degrees at 7 degrees posterior slope. Excessive varus alignment may result in decreased survivorship of prosthesis. Use of more than one pin is beneficial to prevent deviation from desired coronal alignment in systems with increased posterior slope and demonstrates that verification of the tibial cut is critical intraoperatively especially if using a single pin for fixation. Additionally, these variations can be recognized by computer navigation and can allow for intraoperative correction. As further long-term data emerges regarding improved survivorship and outcomes in patients following TKA using computer navigation, the relationship observed in this study between posterior slope and coronal alignment may help explain why navigation leads to increased survivorship and outcomes.

Conflict of Interest

J.W.M. reports he is a consultant for Medacta And has no relationship to this study. J.T.M. reports other from DePuy, other from Corin, other from Stryker, other from Corin, other from Think Surgical, from United Orthopaedics, outside the submitted work.

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