Surgical Alteration of the Coronal and Axial Knee Alignment During TKA Correlates with Reduced Patient Reported Outcomes

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Abstract

Background: Alignment strategies that seek to recreate the native joint in Total Knee Arthroplasty (TKA) are gaining interest as a potential means of reducing post-operative patient dissatisfaction. Due to a lack of routine 3D imaging however, the effect of modifying joint geometry on outcome is not well understood.

Questions/Purposes: The purposes of this study are (1) to determine the degree of modification to anatomy of the axial and coronal joint-line following TKA surgery on a sample of surgeons practicing their standard technique and (2) to investigate if correlation trends and a threshold joint line modification window can be defined to optimise patient outcome as measured by the Knee Injury and Osteoarthritis Outcome Score (KOOS).

Methods: This study retrospectively investigated TKA patients from a joint registry. All patients had pre- and post-operative CT scans, and post-operative KOOS scores obtained at least 6 months after surgery. The change in axial and coronal joint-line following surgery and its relationship to KOOS pain and symptoms was analysed.

Results: Significant but weak correlations were found for the absolute change in femoral coronal alignment (r = -0.141, p = 0.002), coronal joint-line angle (r = -0.140, p = 0.007), and femoro-tibial mismatch (transsepicondylar axis to Insall’s) with KOOS symptoms (r = -0.134, p = 0.011). Patients with a change in coronal femoral or joint-line angle of < 3° reported significantly higher KOOS symptoms scores (difference 4.2 and 3.6 points, p = 0.006 and p = 0.035 respectively), those with a change in axial femoral and femoro-tibial mismatch angle < 6°, also reported significantly higher KOOS symptoms scores (difference 6.7 and 3.8 points, p = 0.019 and p = 0.032 respectively).

Conclusion: Greater modification of the native anatomy correlated with worse TKA symptomatic outcomes however, due to the dynamic nature of the joint, the relationship is complex. Alignment strategies that aim to recreate the patient specific pre-operative anatomy may result in improved outcomes.

Introduction

Despite Total Knee Arthroplasty (TKA) revision rates decreasing, a significant proportion of patients report poor outcomes and dissatisfaction following TKA [1-3]. Patients who are likely to be dissatisfied following surgery tend to have higher preoperative pain, lower functional scores, have suffered postoperative complications [3], and have unmet expectations [4]. There is agreement that successful TKA requires consideration of the alignment of the femoral and tibial components of the knee [5, 6] in both the coronal and axial planes. However, the interpretation of what “ideal alignment” means can vary between surgeons, clinicians and researchers. The optimal alignment approach to be used is currently the subject of debate, with the major options under consideration being Mechanical Alignment (MA) and Kinematic Alignment (KA).

MA attempts to reconstruct the knee and balance compartmental loads, achieving alignment within 3° of the neutral mechanical axis coronally [7]. Axial alignment is achieved by one of two main surgical strategies, gap balancing and measured resection [8, 9]. While this approach has long-term survivorship, patient dissatisfaction remains a concern [10]. Computer navigation [7, 11] and patient specific instrumentation can assist in achieving a neutral postoperative mechanical axis following TKA [7, 12], and has resulted in reduced outlier component placement [13], but not necessarily improved outcomes [14-17]. Conversely, KA attempts to restore the
In the debate between reconstruction vs. restoration, the fact remains that some osteoarthritic (OA) knees have wear and a level of deformity and pathology that makes restoration impossible [19]. However, if reconstructed using MA, this scenario would alter significantly the native anatomy and functionality, which may also result in poor outcomes. Furthermore, the degree to which modification of coronal and axial alignment impacts patient outcome is currently not well understood. Therefore, the aims of this study were as follows: (1) to determine short term relationships between the Knee Injury and Osteoarthritic Outcome Score (KOOS) at 6 months post-surgery and changes in the joint line angle, coronal and axial alignment of the knee resulting from TKA; (2) To investigate if a clinically relevant axial and coronal alignment window exists for improved patient outcomes.

Methods

Patients who received a TKA with pre- and post-operative CT scans, and KOOS scores at least 6 months post-surgery from January 1 2014 to June 30 2018 were selected from the 360 Knee Systems Joint Registry for an exploratory data audit. A total of 372 patients were identified satisfying all requirements, in which 62% (229) were female, with an average age of 69.8 ± 8.1 years.

Surgery was performed by multiple surgeons using a variety of techniques. Surgeons targeted a mixture of mechanical and kinematic alignment but may have made intra-operative adjustments in line with their standard technique. This exploratory data audit did not isolate a single alignment technique or surgeon in order to find results reflective of a general population of implanted TKAs. All patients received either a CR or PS OMNI APEX prosthesis (OMNIls, Raynham). Inclusion criteria were patients receiving a primary TKA for end stage OA. Exclusion criteria were patients receiving any other type of knee arthroplasty, or a diagnosis of rheumatoid-arthritis. Ethics approval for this registry was provided by Bellberry ethics: 2012-03-710.

A CT scan was obtained for pre-operative planning. A post-operative CT scan was obtained to determine the final component positioning and change in joint geometry. The CT scans were a full leg pass from hip to ankle obtained at most 6 months before and after surgery. All scans were taken at 1.25 mm slice thickness, with the coronal and sagittal thicknesses varying but less than 1.0 mm. Segmentation of the femur, tibia and patella bone were performed using ScanIP software (Simpleware, Exeter, UK) to generate a 3-dimensional computational model of the knee, which was then landmarked by 2 engineers.

Patient specific axes of the femur and tibia were then defined from the obtained landmarks according to the method previously described by Twiggs et al. [24]. In each of the coronal and axial planes, a measurement was determined relating to femur alignment only (Lateral Distal Femoral Angle & Femoral Axial Alignment) and tibial alignment only (Medial Proximal Tibial Angle & Tibial Axial Alignment). Furthermore, measurements were calculated for the femoral and tibial combined alignment (Hip-Knee-Ankle Angle and Combined Femoro-Tibial Angle (FTA) and their relationship to each other (Combined Joint Line Angle and Femoro-Tibial Mismatch (FTM)). All measurements are described graphically in Table 1 (coronal) and Table 2 (axial) and were defined in such a way that a post-operative measurement could also be calculated. The pre-operative bone models were then registered to the post-operative CT and corresponding landmarks transformed. Implant geometries were registered to the post-operative CT scan using the +CAD module within ScanIP. The implant positions were then combined with the bone geometry and landmarks to generate the final joint geometry and compared to the pre-operative state as described by Wakelin et al. [25]. The workflow for this process is shown in Figure 1.
Table 1: Definitions and examples of coronal anatomic measures investigated.

<table>
<thead>
<tr>
<th>Anatomic Measure</th>
<th>Definition</th>
<th>Modification for Post-op analysis</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Femoral Coronal Alignment (Lateral Distal Femoral Angle, LDFA)</strong></td>
<td>Angle between the line joining the distal femoral condyles and the femoral mechanical axis. Positive values indicate valgus.</td>
<td>Landmarks defining femoral condyles are replaced by prosthesis condyle points.</td>
<td></td>
</tr>
<tr>
<td><strong>Tibial Coronal Alignment (Medial Proximal Tibial Angle, MPTA)</strong></td>
<td>Angle between the line joining the proximal tibial condyles and the mechanical axis of the tibia. Positive values indicate varus.</td>
<td>Landmarks defining tibial condyles are replaced by prosthesis condyle points.</td>
<td></td>
</tr>
<tr>
<td><strong>Hip-Knee-Ankle Angle (HKA)</strong></td>
<td>Angle between the femoral and tibial mechanical axes as observed in the CT.</td>
<td>No change.</td>
<td></td>
</tr>
<tr>
<td><strong>Combined Joint Line Angle (JLA)</strong></td>
<td>The average between the femoral and tibial coronal angles. Positive values indicate medial down slope.</td>
<td>Landmarks defining femoral and tibial condyles are replaced by prosthesis condyle points.</td>
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</tr>
</tbody>
</table>
Table 2: Definitions and examples of axial anatomic measures investigated.

<table>
<thead>
<tr>
<th>Anatomic Measure</th>
<th>Definition</th>
<th>Modification for Post-op analysis</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral Axial Alignment</td>
<td>Angle between the line joining the posterior femoral condyles (PCA) and the surgical transepicondyle axis (TEA). Positive values indicate externally rotated TEA.</td>
<td>Landmarks defining posterior femoral condyles are replaced by prosthesis posterior condyle points.</td>
<td><img src="image" alt="Example" /></td>
</tr>
<tr>
<td>Tibial Axial Alignment</td>
<td>Angle between Insall’s and Cobb’s definition of tibial rotation. Positive indicates internally rotated Cobb’s line.</td>
<td>Landmarks defining tibial condyles are replaced by prosthesis condyle points.</td>
<td><img src="image" alt="Example" /></td>
</tr>
<tr>
<td>Combined Femoro-Tibial Angle (FTA)</td>
<td>Average of Insall’s line and the surgical transepicondylar axis (TEA) referenced to the PCA.</td>
<td>PCA defined as in Femoral Axial Alignment, all other measurements native.</td>
<td><img src="image" alt="Example" /></td>
</tr>
<tr>
<td>Femoro-tibial Mismatch (FTM)</td>
<td>Angle between the TEA and a line perpendicular to Insall’s definition of tibial rotation.</td>
<td>No change.</td>
<td><img src="image" alt="Example" /></td>
</tr>
</tbody>
</table>

Post-operative KOOS scores were obtained at least 6 months post-surgery, in line with findings from a previous study by Judge et al. [26]. Patients were asked to consider the previous seven days as a time frame. Linear Spearman’s correlations between the KOOS Symptoms subscores (scores out of 100, with more positive values being a better outcome), and change in coronal and axial femoro-tibial and combined knee alignments were determined. The change in coronal angles were subdivided into patients with a change less than 3° from native and those with a greater change, consistent with the use of 3° from the mechanical axis as a metric for accurate MA attainment [27]. For the axial measurements, this threshold was doubled to 6° given the known reduced accuracy of rotational alignment [28, 29]. The resultant groups created were then t-tested for difference. Significance was set to p = 0.05 and all statistical analysis was performed with R 3.4.2 [30].

Results

Trends in Anatomical Recreation of the Joint Line

Figure 3 shows the pre-operative and post-operative measurements in the coronal plane for the tibial varus, femoral valgus, HKA and JLA. Table 3 shows the mean, standard deviation and range of each of these measurements as well as the pre- to post-operative change. In all measurements the trend is for implanted angles to have a lower magnitude than pre-operatively.

Figure 4 Shows the pre-operative and post-operative measurements in the axial plane for the tibial, femoral, FTA and FTM angles. Table 4 shows the mean, standard deviation and range of each of these measurements as well as the pre- to post-operative change. The tibial, femoral and FTA all display post-operative variation independent of the pre-operative state. The post-operative FTM show a trend towards retaining the native alignment post-operatively.
Table 3: Statistical details of Femoral and Tibial coronal angles pre-operatively, post-operatively, and change.

<table>
<thead>
<tr>
<th></th>
<th>Preop</th>
<th>Postop</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral Coronal Alignment</td>
<td>2.93 ± 2.52°</td>
<td>0.68 ± 2.07°</td>
<td>2.62 ± 2.09°</td>
</tr>
<tr>
<td>(LDFA)</td>
<td>(-7.28 to 10.22)</td>
<td>(-4.64 to 7.13)</td>
<td>(0 to 9.55)</td>
</tr>
<tr>
<td>Tibial Coronal Alignment</td>
<td>3.75 ± 2.98°</td>
<td>1.04 ± 1.75°</td>
<td>3.33 ± 2.22°</td>
</tr>
<tr>
<td>(MPTA)</td>
<td>(-7.38 to 12.73)</td>
<td>(-3.67 to 5.85)</td>
<td>(0.02 to 10.4)</td>
</tr>
<tr>
<td>Hip-Knee-Ankle Angle</td>
<td>4.13 ± 5.48°</td>
<td>1.30 ± 2.47°</td>
<td>4.46 ± 2.8°</td>
</tr>
<tr>
<td>(HKA)</td>
<td>(-12.11 to 17.58)</td>
<td>(-6.8 to 7.68)</td>
<td>(0.01 to 11.92)</td>
</tr>
<tr>
<td>Combined Joint Line Angle</td>
<td>3.34 ± 1.73°</td>
<td>0.86 ± 1.56°</td>
<td>2.67 ± 1.69°</td>
</tr>
<tr>
<td>(JLA)</td>
<td>(-2.28 to 8.31)</td>
<td>(-2.62 to 4.81)</td>
<td>(0.02 to 8.18)</td>
</tr>
</tbody>
</table>

Figure 2: Comparison of the pre- and post-operative coronal plane measurements for femoral alignment (a), tibial alignment (b), overall long leg alignment (c) and joint line (d) angles.
Figure 3: Comparison of the pre- and post-operative axial plane measurements for femoral alignment (a), tibial alignment (b), combined femoro-tibial (c) and femoro-tibial mismatch (d) angles.

Table 4: Statistical details of Femoral and Tibial axial angles pre-operatively, post-operatively, and change.

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</tr>
</thead>
<tbody>
<tr>
<td><strong>Femoral Axial Alignment</strong></td>
<td>2.04 ± 1.72°</td>
<td>2.14 ± 2.36°</td>
<td>2.57 ± 1.89°</td>
</tr>
<tr>
<td></td>
<td>(-2.44 to 6.48)</td>
<td>(-3.45 to 8.42)</td>
<td>(0.01 to 8.42)</td>
</tr>
<tr>
<td><strong>Tibial Axial Alignment</strong></td>
<td>5.56 ± 3.88°</td>
<td>3.16 ± 4.73°</td>
<td>4.7 ± 3.34°</td>
</tr>
<tr>
<td></td>
<td>(-7.83 to 16.19)</td>
<td>(-10.92 to 18.59)</td>
<td>(0 to 17.36)</td>
</tr>
<tr>
<td><strong>Combined Femoro-tibial Angle</strong></td>
<td>8.91 ± 5.33°</td>
<td>4.98 ± 5.2°</td>
<td>4.94 ± 3.49°</td>
</tr>
<tr>
<td></td>
<td>(-6.91 to 23.28)</td>
<td>(-8.05 to 24.03)</td>
<td>(0 to 16.58)</td>
</tr>
<tr>
<td><strong>Femoro-tibial Mismatch (FTM)</strong></td>
<td>6.50 ± 3.17°</td>
<td>3.44 ± 2.55°</td>
<td>3.83 ± 2.79°</td>
</tr>
<tr>
<td></td>
<td>(-3.22 to 15.67)</td>
<td>(-3.53 to 11.14)</td>
<td>(0.03 to 14.58)</td>
</tr>
</tbody>
</table>
Thresholds for Outcome Improvement

The mean postoperative KOOS Pain Score was 84.7 +/- 16.9 and KOOS Symptoms Score was 79.2 +/- 16.5. Histograms of the scores for the population are shown in Figure 2. Both scores are right shifted, with the lower mean score for KOOS Symptoms indicating a smaller fraction of patients scoring 100.

There was a significant but weak correlation between the absolute change in the femoral component coronal alignment and KOOS symptoms scores ($r = -0.141, p=0.002$) as well as the change in the joint line angle and KOOS symptoms scores ($r = -0.140, p=0.007$), in which the greater the change, the worse the KOOS scores. The change in femoral coronal angle and change in joint line were subdivided into groups in which the change was less than or greater than 3$^\circ$ and plotted against the KOOS Symptoms scores in Figure 5. The patients in which the change in femoral coronal and joint line angle was less than 3$^\circ$ reported statistically significantly improved outcomes (Coronal femoral angle change: $p=0.006$ and joint line change: $p=0.035$ respectively).

Figure 4: Six months postoperative KOOS Score distributions for the KOOS Pain subscore (a) and KOOS Symptoms subscore (b). Both distributions are significantly right shifted (low pain/symptomatic issue), with pain having generally higher scores than symptoms.

Figure 5: Violin plot of the change in coronal femoral angle (a) and joint line (b) subdivided into groups in which the change is less than or greater than 3$^\circ$ against KOOS symptoms. In both cases, patients with less than 3$^\circ$ change report statistically significantly improved outcomes. (Coronal femoral angle change: $p=0.006$ and joint line change: $p=0.035$).
There was a significant but weak correlation between the change in FTM (TEA to Insall’s) and KOOS symptoms \((r=-0.134, p=0.011)\) as well as the change in the FTA and KOOS pain \((r=-0.138, p=0.008)\). When thresholded, in Figure 6, patients in which the change in the femoral axial alignment and femoro-tibial mismatch was less than 6° reported significantly higher KOOS symptoms scores post-operatively (difference = 6.7, \(p=0.019\) and difference = 3.8, \(p=0.032\) respectively).

**Figure 6:** Violin plot of the change in axial femoral angle (a) and tibio-femoral angle (b) subdivided into groups in which the change is less than or greater than 6° against KOOS symptoms. In both cases, patients with less than 6° change report statistically significantly improved outcomes. (Axial femoral change: \(p=0.019\) and femoro-tibial mismatch change: \(p=0.032\) respectively)

### Discussion

Due to the lack of routine pre- and post-operative CT imaging, accurate measurement of the modification of coronal and axial alignment following TKA surgery has not been possible. By analysing such imaging in conjunction with PROMS, the impact of alignment decisions on outcome can be investigated. Significant correlations between femoral coronal, coronal joint line, FTM and FTA angles and KOOS symptoms were found, in which increased modification of the anatomy correlated with worse outcomes. An absolute difference in femoral coronal and coronal joint line angles of less than 3° and axial femoral and FTM angles of less than 6° resulted in significantly improved KOOS symptoms compared to those outside of this threshold, indicating alignment philosophies that aim to recreate the native anatomy may improve outcomes.

Improper positioning of components in TKA at the extremes can result in poor patient-reported outcomes (PROMS) [31, 32] and reduced ROM [33], but the exact mechanism by which this occurs is not simple. One possible explanation for restriction in ROM after TKA is an inability of soft tissue to achieve flexion/extension balance in the new dynamic environment, leading to excessive stiffness or instability. The finding here, that changes in femoral articulation angle and associated femoro-tibial angular relationships (joint line and FTA angle) correlated with outcome but tibial measurements and combined femoro-tibial measurements (Hip-Knee-Ankle and FTM angle) did not supports this hypothesis. For instance, a valgoid placement of the femoral component may lead to looser lateral structures, such as the LCL, when the knee is in extension but no change when in flexion. Conversely, when the femoral component is placed in external rotation from the PCA – typical in MA when targeting the TEA - the result is tighter lateral structures when the knee is in flexion but no difference when the knee is in extension, coro-

coronal alignment being held constant. Such changes result in a dynamic joint gap, in which soft tissue may be incapable of adapting to the new environment, affecting joint balance [34]. Conversely, a tibial angular change postoperatively will loosen or tighten structures in both flexion and extension and soft tissue adaptation may occur more readily in this environment due to the balanced nature of the modification.

Changes in the coronal plane of more than 3° and in the axial plane of more than 6° from pre-operative anatomic measurements show a significant decrease in the post-operative KOOS symptoms scores. Dosset, Salzmann and Vanlommel [35-37] have observed improved functional scores in patients undergoing a KA TKA, a similar finding to those here. The strength of the present study however, in comparison to the outcomes found in the existing literature is that all measurements are referenced to reconstructed pre-operative anatomy, allowing identification of postoperative changes in the anatomic angles of the femur and tibia individually as well as their relationships to each other.

The final alignment measured using this technique is a combination of the planned alignment, the surgeon’s decision based on intraoperative observations, and variability in component placement. For this reason, the threshold values were chosen to reflect the level of accuracy that can be expected for a target alignment parameter. Intraoperative observation is a crucial element in decision making at the time of surgery. For instance, the patient cohort in this study were OA subjects in which the joint line may have been affected by the disease progression and may therefore be pathological. In this population, a change in joint line may be required in significantly deformed patients to target any alignment philosophy. Within this study however, the difference between intentional philosophy driven component placement and random variability cannot be distinguished.
While MA is still the preferred approach amongst most surgeons, when the native alignment is outside an established threshold, greater ligament release is likely needed during surgery to achieve balance. However, this approach appears to negatively impact symptomatic outcomes and may introduce undesirable knee kinematics such as post-operative instability [11, 38, 39]. Literature indicating improved functional outcomes with kinematically aligned TKA components [22, 40], combined with the present findings, indicate patients tend to prefer more native knee alignments, rather than mechanically stable neutrally aligned components. This may be due to more balanced ligament forces throughout the flexion cycle without the need for ligament release, although other studies have shown no difference in functional outcomes between patients with post-operative residual varus and those with neutrally aligned TKA [41, 42]. A recent meta-analysis has found improved functional outcomes in KA patients [43], indicating that although debate remains on the optimal TKA alignment strategy, MA may not be ideal for every patient.

For patients in which the native anatomy requires component alignment that is far from neutral, further analysis of the optimal surgical compromise is required. Furthermore, in cases of severe bone erosion, a patient’s pre-osteoaarthritic alignment may be difficult to determine without historical imaging. These instances have led to the development of restricted kinematic alignment (rKA), which enforces limitations on target alignments [10, 19]. In cases in which the prearthritic alignment is outside such limits, rKA will not achieve the complete anatomical restoration of KA or the reconstruction to neutral of MA and a compromise between reconstruction and restoration is performed. As a result, the behavior of restricted kinematic alignment is to reduce the deviation in anatomy brought on by the TKA surgery more in patients with native anatomy closer to MA than further away. Based on the results from this study, reducing the deviation from native anatomy as far as practicable results in improved functional outcomes, lending strength to opting for KA approaches over MA or rKA in patients where native anatomy deviates more from MA.

There are a number of limitations to this study. First, this study combines data from different techniques from 12 different surgeons and as such is not a controlled analysis of the performance of a single operating technique. However, this limitation also shows the observed effect to exist across some of the variability in practice across the industry, adding confidence to the population results. Caution must be taken in interpreting findings with a specific implant design and alignment combination, and further research is called for. Related to this (and limiting the strength of the population sample) is that the sample is confined to an Australian population, which may have differences from other population groups. Third, the pre-operative anatomy was measured using CT scans, and as such, the analysis does not include information on cartilage, whose wear is included in the establishment of OA. Thus, the joint line was not exactly identified, but the deviation from native anatomy as far as practicable results in improved outcomes. This study and the evidence found in the literature suggest alignment techniques that recreate native anatomy may have some advantages over alignment techniques that do not.

Conclusion

Total knee arthroplasty outcomes are multifactorial and dependent on the femoral and tibial component alignment in the sagittal, coronal and axial planes. Alternative alignment strategies are gaining interest as a means to reduce the persistently high dissatisfaction rate in TKA. This study utilises pre- and post-operative analysis of patient anatomy to determine the change in knee axial and coronal alignment. Greater differences between pre- and post-operative anatomy were negatively correlated with KOOS pain and symptoms, indicating that matching the prosthesis to the native anatomy may result in improved outcomes. This study and the evidence found in the literature suggest alignment techniques that recreate native anatomy may have some advantages over alignment techniques that do not.

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