Tibial component rotation alters soft tissue balance in a cruciate retaining total knee arthroplasty

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ABSTRACT

Our aim was to understand whether using different landmarks for tibial component rotation influenced articular contact pressures in a balanced total knee arthroplasty (TKA). Twelve patients underwent TKA (Triathlon CR, Stryker Inc., Mahwah, NJ) and contact pressures were assessed using a wireless sensor. Robotic arm assisted TKA using a functional alignment technique was performed, with balanced gaps between medial and lateral compartments. Compartment pressures were measured with the trial tibial component rotated to Akagi’s line and to Insall’s axis respectively. Rotating the tibial component to Akagi’s line resulted in a significantly greater proportion of knees being balanced and lower contact pressures than when the tibial component was aligned to Insall’s axis at 10\(^\circ\), 45\(^\circ\) and 90\(^\circ\) of flexion (\(p<0.05\)). Medial compartment pressures were significantly increased in 10\(^\circ\) of flexion, as were lateral compartment pressures in all positions when the tibial component was aligned to Insall’s axis (\(p<0.05\)). The mean difference in rotation observed with the two landmarks was 6.9\(^\circ\) (range 4.1–9.1\(^\circ\)). Rotational alignment of the tibial component using Akagi’s line reduced contact pressures, improved balance and reduced the need for soft tissue release when compared with Insall’s axis in robotic arm assisted TKA.

KEYWORDS

Tibial rotation; total knee arthroplasty balance; sensor balance; robotic assisted total knee arthroplasty

Introduction

Rotational alignment has been shown to be highly variable both in the native knee, and after total knee arthroplasty (TKA) [1,2]. The optimal femoral and tibial component rotation during TKA has been discussed for decades without reaching a consensus. Rotational malalignment may cause patellar maltracking, anterior knee pain, loss of extension, femorotibial instability and the increase tibio-femoral contact pressures causing polyethylene wear [3–5]. Determination of optimal component rotation would reduce articular contact pressures and minimize polyethylene wear [6,7].

Three options for tibial component placement have been summarized by Scott [8]: using the best tibial cut surface coverage, tibial tubercle anatomy or femoral component rotation.

Aligning the tibial component with the medial third of the tibial tubercle is the most widely used method, but the literature published to support the theory behind this technique is not conclusive. There are studies that have reported excessive external rotation of the tibia relative to the femur using the tibial tubercle as an alignment landmark [9,10].

Until recently, TKA surgeons have had limited resources for understanding the relationship between alignment and tibiofemoral load transfer. In manually-aligned TKA, surgeons continue rely on anatomic landmarks as indicators of functional axes of the femur and tibia. But, there are inter-individual anatomic variations in limb alignment [11,12]. For example, in the Japanese population there is increased medial torsion of the tibia [13], and there is variability in tibial tubercle morphology across patients [14]. These variations can explain why anatomical landmarks fail to be reliable. Recent advances in imaging, navigation, robotics and sensors have started to provide intraoperative information to bridge this gap in knowledge.

Two of the most referenced tibial landmarks for tibial component rotation are Insall’s axis (from the PCL insertion to the medial one third of the tibial tubercle) [15] and Akagi’s line (from the PCL to the medial border of the Patella tendon) [9].
Table 1. Contact pressure results obtained for each tibial rotation with mean pressures (Psi) and range in brackets.

| Degrees of knee flexion | Compartment | Akagi’s line | Insall’s axis | p Value (t-test) |
|-------------------------|-------------|--------------|---------------|-----------------|
| 10°                     | Medial      | 18.3 (6–36)  | 33.7 (8–63)   | 0.049           |
|                         | Lateral     | 15.9 (5–37)  | 40 (11–124)   | 0.018           |
|                         | Difference  | 5.2 (0–13)   | 25.5 (2–61)   | <0.001          |
| 45°                     | Medial      | 18.3 (6–44)  | 32.2 (5–94)   | 0.115           |
|                         | Lateral     | 12.7 (6–35)  | 27.8 (7–81)   | 0.038           |
|                         | Difference  | 10.8 (1–30)  | 27.6 (5–76)   | 0.023           |
| 90°                     | Medial      | 20.3 (8–82)  | 30.7 (6–134)  | 0.392           |
|                         | Lateral     | 13.6 (5–36)  | 34.6 (10–85)  | 0.008           |
|                         | Difference  | 13.5 (1–76)  | 34.9 (10–117) | 0.060           |

Bold values were the significant values with p < 0.05

The articular load measuring device utilized in this study has previously been assessed and compartment pressures are recommended to be below 30 psi in each compartment. Balance between compartments has been defined as a difference of <15 psi [16,17]. These sensors and this technique have been validated with low intra- and inter-observer variability [18].

Our aim was to compare these landmarks for tibial component rotation (Insall’s axis and Akagi’s line) by measuring contact pressures through the range of motion. The landmark with the most balanced contact pressures would determine the rotation for implantation. We combined enhanced computed tomography (CT) planning of tibial alignment with an intra-operative knee sensor to achieve this goal. A secondary aim was to determine if pre-resection balancing technique utilized for robotic arm assisted functionally aligned TKA system would result in balanced pressures.

Material and methods

Twelve patients underwent robotic TKA by a single surgeon utilizing a disposable articular load measuring device (VERASENSE Knee System, OrthoSensor Inc., Dania Beach, FL) to assess soft tissue balance. All patients had the original diagnosis of osteoarthritis with varus deformity. Each patient was enrolled in a prospective clinical registry (SJGHC HREC approval no.1388) to enable post-surgical analysis of intra-operative data obtained. A medial parapatellar approach was utilized. Balancing was performed using functional alignment with robotic assistance (Mako, Stryker Inc., Mahwah, NJ) [19], with adjustments to bone cuts to allow a maximum of 1 mm difference between medial and lateral projected gaps. No further soft tissue releases were required in any of the 12 cases to balance the knee. Femoral valgus angulation had a mean value of 2.3° (0°–5° valgus) and tibial component varus angulation averaged 3.4° (2° valgus to 6° varus) Femoral component rotation was aligned to within 3° of the surgical trans-epicondylar axis for all patients with femoral rotation being adjusted to balance flexion gap. The same TKA design was used in all cases (Triathlon CR, Stryker Inc., Mahwah, NJ).

To determine the optimal tibial component rotation for each patient, contact pressures were assessed using a wireless, disposable articular loading device which was inserted into the tibial component tray during the trialing phase of surgery. The sensor provides information on compartment pressures in both the medial and lateral compartments in pounds per square inch (psi).

For all patients the same protocol was used to acquire contact pressure measurements with the sensors. The rotational landmarks were marked with cautery at the edge of the tibial cut using the sensor probe to locate the landmark from the pre-operative CT scan. The rotational variation between the positions was measured with the robotic software from the CT scan. The tibial trial was first pinned in rotational alignment to Insall’s axis. The surgeon held the leg with the foot and patella facing anteriorly and then bent the knee from full extension to full flexion. Compartment pressures were recorded at 10°, 45° and 90° of flexion. The tibial trial was then rotated to Akagi’s line, and the same protocol was used to acquire contact pressures. The surgeon was blinded to measurements from the sensor during acquisition of the values and only given values once both rotations were assessed. The more balanced tibial component position was used for implantation.

Continuous variables were summarized using means and ranges, and a two sample Student t-test was used to find differences in the compartmental pressures. The chi-square test was used to determine differences in the proportion of knees balanced at any given degree of flexion for each rotational alignment and the proportion in which maximal pressures exceeded recommended levels. Post-hoc power analysis was undertaken on this sample (using...
intercompartmental pressure difference at 10° as the primary outcome) as there were no available values to calculate sample size prior to the study. This indicated it was fully powered (power = 1.00) with an alpha error of 0.05 and the sample size required was 2 patients given the magnitude of difference detected.

**Results**

Mean medial compartment contact pressures were reduced at 10° of flexion when the tibial tray was aligned according to the medial border of the patellar tendon (p = 0.049), but the differences in these values did not reach significance at 45° and 90° of flexion. In the lateral compartment, there was a significant reduction in contact pressure at all positions tested with rotation to Akagi’s line when compared to Insall’s axis (p = 0.018, 0.038 and 0.008 at 10°, 45° and 90°, Table 1).

The proportion of knees within optimal recommended pressures (<30 psi) [16] were significantly greater at 10° flexion and 90° flexion when the tibial component was rotated to Akagi’s line (Table 2).

When considering balance, or inter-compartmental differences, all patients had less than 15 psi difference at 10° flexion with the tibial component rotated to the medial border of the patellar tendon compared to only 5 patients having balance when rotated relative to the tibial tubercle (p = 0.002). There was significantly greater proportion of patients balanced with the tibial component rotated to Akagi’s line at all positions of flexion measured (Figure 1). Eleven of twelve knees tested were balanced with optimal pressures in 10° flexion and 9 of 12 in 90° flexion when aligned to Akagi’s line. This compares to 5 in 10° flexion and 3 in 90° flexion utilizing Insall’s axis for rotational alignment (Table 3).

The mean difference in tibial tray rotation between the two positions was 6.9° greater external rotation with rotation to the medial third of the tibial tubercle, with a range of 4.1° to 9.1°.

**Discussion**

Variation in tibial component rotation does affect the contact pressures in TKA as shown in this study. This variation can result in significant differences in pressures between medial and lateral compartments despite the gap measurements being equal at both full extension and 90° flexion. This suggests that tibial rotation, while traditionally overlooked, is an important consideration to achieve an accurately balanced TKA.

The result also suggests that even a small difference in tibial rotation has a significant impact on the intra-articular contact pressures. In this study there was a mean difference of less than 7 degrees (rotated from PCL insertion) yet this was enough to make greater than 50% of knees unbalanced when assessed with a load sensor as per Gustke’s technique [16,17]. The difference in rotation is amplified if measured from the mid-point of the tibial base plate.

In TKA design with a relatively flat tibial insert (such as the Triathlon CR insert used in this study) it is the surrounding soft tissues that determine the rotational relationship between the femur and the tibia. There is not enough constraint in the design for it to be considered possible that the rotation of the tibial insert can alter this relationship.

Thus altering tibial rotation alters contact points between the femur and tibia. External rotation of the tibia will move the lateral compartment contact point anteriorly and the medial compartment contact point posteriorly. This malalignment between the femoral and tibial components means the femoral component no longer sits within the deepest part of the polyethylene insert. This has previously been demonstrated in a cadaveric model to increase pressures with further external rotation of the tibial base plate [20].

It has been reported that tibial tray internal rotation can have significant negative impact on patellofemoral tracking [3] and clinical outcomes. The literature suggests that there is as little as 5° difference in rotation between TKA patients with and without patella-tracking complications and anterior knee pain [3,21,22]. The measurement of tibial rotation has always been relative to the tibial tubercle in these studies. What has not been established is whether the reported internal tibial rotation is simply a surrogate for a lateraled tibial tubercle. An alternative interpretation of these results is that patients with lateraledized tibial tubercles have poor patellofemoral tracking.

The inability of an unconstrained insert to alter tibiofemoral rotation would suggest it has little effect.
on patellofemoral tracking. The patellofemoral relationship will be affected by the native anatomy (tuber-
cle lateralisation) and the femoral component position and morphology. This area will require more study.

Given the variability in the position of the tibial tubercle and the need for rotational congruence with
the femoral component it may be more appropriate for the femoral landmarks to be used to determine
the tibial rotation. Care must be used in utilizing the femoral landmarks on pre-operative CT scans as they
are non-weightbearing and the ACL is usually intact which may alter the femorotibial relationship seen in
the post-operative TKA. Utilizing the trial femoral component to guide tibial rotation is acceptable if there is
a neutral tibial cut. If there is slope or coronal angulation in the tibial cut then rotation is best deter-
mined prior to the cut as altering tibial rotation after the cut is made will alter desired coronal alignment
and slope and therefore balance as demonstrated in this study.

The medial border of the patella tendon more closely replicates the rotation of the surgical epicondy-
lar axis when compared to the medial one third of the tibial tubercle [10,23,24]. This is likely to explain the
improved balance and reduced contact pressures as utilizing the medial border of patella tendon leads to
less femorotibial mismatch and the contact points between implants being more symmetrical as the
implant design intended. Ideally the tibial rotation should be related to the final position of the femoral
component but this relationship has yet to be incor-
porated into the optic tracking software utilized.

The results of this study demonstrate that tibial rotational malalignment can render a TKA with bal-
anced gaps in extension and flexion unbalanced when assessed with pressure sensors. It does also show that
the technique of virtually balancing the knee prior to bone resection then executing bone cuts with robotic

Table 3. Number of TKA balanced at each tibial rotation (n = 12 patients).

| Knee flexion | Tibial component rotation | p Value (chi-square) |
|--------------|---------------------------|---------------------|
| 10°          | Akagi’s line              | 12                  | 0.002               |
|              | Insall’s axis             | 5                   |                     |
| 45°          | Akagi’s line              | 8                   | 0.013               |
|              | Insall’s axis             | 2                   |                     |
| 90°          | Akagi’s line              | 9                   | 0.014               |
|              | Insall’s axis             | 3                   |                     |

Bold values were the significant values with p < 0.05
arm assisted technology can reliably produce a balanced TKA. Although an early study using sensors showed improved outcomes [17], there has been conflicting evidence in more recent comparative trials [25–27]. This study would suggest that balanced gaps as measured with optic trackers and avoidance of rotational mismatch may be sufficient to reliably establish balance in TKA.

This study has several limitations. The number of patients studied was small, but it was adequately powered to detect a pressure difference of 15 psi in extension. Secondly, the measurements were performed by a single surgeon. These were blinded to avoid bias and reproducibility of these sensor measurements have previously been validated [18]. Finally, the femoral component rotational position was varied for soft tissue balance in each knee. This will have an effect on the contact pressures and tibiofemoral mismatch, and although not standardized, this was controlled for by the paired nature of the samples.

**Conclusion**

Our results show that small variations in tibial tray rotation, can have large effects on contact pressures within the knee. This study favors the use of the medial border of the patellar tendon (Akagi’s line) as the tibial rotation reference in preference to the medial one third of the tubercle (Insall’s axis) in order to obtain a more balanced knee. This study does show that a pre-resection balancing technique utilizing robotic arm assisted technology can reliably achieve balanced pressures between compartments. A more reliable method than the use of tibial landmarks to identify appropriate tibial rotation for each TKA is required. Future TKA research will move toward using advanced technologies to measure knee kinematics, plan component alignment pre and intra operatively with the aim of optimizing balance and kinematics of the TKA designs.

**Acknowledgements**

Bethany Tippett – data collection.
Christina Esposito – manuscript editing and proof reading.

**Disclosure statement**

In accordance with Taylor & Francis policy and my ethical obligation as a researcher, I(GC) am reporting that I am a consultant to Stryker Orthopedics, a company that may be affected by the research reported in the enclosed paper. I have disclosed those interests fully to Taylor & Francis, and I have in place an approved plan for managing any potential conflicts arising from [that involvement]. No other authors have conflicts of interest to declare. The data that support the findings of this study are available from the corresponding author, [GC], upon reasonable request.

**Funding**

The author(s) reported there is no funding associated with the work featured in this article.

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