The effect of the native kinematics of the knee on the outcome following total knee arthroplasty

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Aims
The aim of this study was to investigate differences in pain, range of movement function and satisfaction at three months and one year after total knee arthroplasty (TKA) in patients with an oblique pattern of kinematic graph of the knee and those with a varus pattern.

Patients and Methods
A total of 91 patients who underwent TKA were included in this retrospective study. Patients (59 women and 32 men with mean age of 68.7 years; 38.6 to 88.4) were grouped according to kinematic graphs which were generated during navigated TKA and the outcomes between the groups were compared.

Results
The graphs were varus in 50 patients (55%), oblique in 19 (21%), neutral in 17 (18.5%) and valgus in five (5.5%). After adjustment for pre-operative scores and gender, compared with patients with varus knee kinematics, patients with an oblique kinematic graph had a poorer outcome with lower Knee Society scores at three months (9.2 points, p = 0.038).

Conclusion
We found four distinct kinematic graphs in knees and that patients with an oblique graph have a poorer outcome in the short-term after TKA.

Cite this article: Bone Joint J 2016;98-B:1471–8.

The optimal alignment in total knee arthroplasty (TKA) remains controversial. The goal of achieving neutral mechanical alignment is long-standing and is based on biomechanical studies in the 1970s. During that time the priority was to achieve the “proper distribution of stress” across the medial and lateral compartments of the knee and thus a low rate of wear.1 Since then there have been significant improvements in the materials used in TKA. The optimal alignment of the components to achieve the best patient reported outcomes with a low rate of revision, however, remains unresolved.

A total of 47 476 primary TKA were performed in Australia in 2014.2,3 The 2015 Australian National Joint Replacement Registry reported a cumulative revision for primary TKA performed for osteoarthritis of 5.5% (95% confidence interval (CI) 5.4 to 5.6) at ten years.4 Although improvement through advancements in surgical technique and implant technology has reduced the number of failures due to infection, aseptic loosening and fracture, there remains a group of patients who have a poor outcome following TKA despite avoiding those complications. It has been shown that factors such as the patient’s expectations of pain relief and functional improvements affects the level of satisfaction following TKA.3,5,6 The underlying cause of a poor outcome when the usual modes of failure are not detected is not well understood. Whilst not always requiring revision, a TKA which is symptomatic may be felt not to have provided significant benefit. Bourne et al5 found 19% of 1703 patients had a satisfaction level of neutral or lower.

There has been conflicting evidence regarding whether using individualised alignment of the kinematic axis improves the clinical outcome. Dossett et al7 reported greatly improved outcomes with this technique compared with mechanical axis alignment whilst Young et al8 showed minimal differences. Both studies were Level 1 randomised control studies and both contained patients in each of the groups with poor outcomes suggesting that predicting which patients would benefit from one surgical technique rather than another is not yet possible.

When performing navigated TKA, one of four different patterns may be noted in the initial kinematic graphs (Fig. 1). First, a standard...
varus graph whereby, the mechanical axis remains varus throughout the extension-flexion arc of movement. Secondly, a valgus graph, when the alignment is valgus throughout the range of movement. In a third, neutral graph, alignment remains within 2° of the neutral axis. Finally, in an oblique graph, the mechanical axis changes from varus to valgus (or vice versa) through the extension-flexion arc of movement.

The objective of this study was to compare pain in the knee, range of movement (ROM), functional outcomes and satisfaction at three and one year after TKA in patients with an oblique pattern on intra-operative kinematic graphs and those with a varus pattern. It was hypothesised that due to changes in the axis of femoral rotation relative to the surgical epicondylar axis, which occurs when a patient with an oblique curve undergoes a mechanical axis TKA, and its effect on the surrounding soft tissue, this subgroup of patients would have more pain, less ROM and poorer function.

Patients and Methods

The study involved a consecutive series of 91 patients (59 women, 32 men; mean age 68.7 years; 38.6 to 88.4) who underwent computer navigated mechanical axis aligned primary TKA without a previous history of osteotomy, at our hospital under the care of the senior author (GWC) between 2008 and 2013, who had full sets of both intraoperative kinematic data from the navigation unit and clinical outcome data. The study was approved by the institutional Human Research Ethics Committee, Reference number 13-179.

Surgery was performed using a medial para-patellar approach through a midline incision with navigation trackers secured to the femur and tibia outside the surgical field. A standard technique was used with the aim of placing the components in neutral alignment relative to the mechanical axis. A computer navigated measured resection technique (Stryker, Kalamazoo, Michigan, Precision Knee Computer Navigation) and Triathlon components, with a single radius of curvature, (Stryker) were used.

A kinematic graph of the joint was recorded using the navigation software. A standardised technique involved taking the joint from full extension to full flexion whilst stressing the joint with a varus and then valgus force through the arc of motion (see video in supplementary material). This produces a graph showing the degree of varus/valgus movement allowed by the soft-tissue envelope and the bone morphology of the knee at each 10° along the arc of motion. This allowed the surgeon to determine if soft-tissue releases were likely to be required in order to create neutral mechanical alignment.

As part of standard care at our institution, outcome measures are routinely collected with clinical assessment pre- and post-operatively at three and 12 months, and two, five and ten years. This study uses the data collected preoperatively and at three and 12 months post-operatively for each patient. These data include the Knee Society Clinical Rating System (KSS),9 containing the Knee Society Knee Score (KSKS) and Knee Society Function Score (KSFS), and post-operative satisfaction scores. Additionally, a group of patients had post-operative CT scans of the leg which were assessed according to the Perth protocol10 for analysis of alignment. The rotation of the femoral component was analysed to assess the possibility that the appearances on the oblique graphs could be explained by malrotation of the femoral component.

Patients were categorised according to their initial kinematic graphs (Fig. 1). Potential confounding factors included gender, age, body mass index (BMI), comorbidities as documented with the Charnley Classification11 and American Society of Anesthesiology (ASA) scores,12 patellar resurfacing and lateral retinacular release at surgery.

In those patients with a CT scan available, the scans were reviewed and the rotation of the femoral component was measured as per the Perth CT protocol.13

Statistical analysis. The oblique group was compared only with the varus group for two reasons. First, patients with varus kinematics are most frequently encountered and therefore acted as a comparison. Secondly, there were few patients in the neutral and valgus groups (n = 17, n = 5, respectively) and so a direct comparison with varus (the most frequent type) reduced heterogeneity in the comparator group and maintained acceptable numbers for analysis. For unadjusted comparisons between groups of baseline data, and KSS component subscores at 12 months, independent t-tests or nonparametric equivalent Wilcoxon rank sum tests were used for continuous data. Wilcoxon rank sum tests were also used for ordinal data and chi-squared or Fisher’s exact tests for categorical data. In order to test the primary hypothesis of differences in KSS scores and function between groups, adjusted estimates of group differences in KSFS scores were performed using a linear regression model of three and 12 month scores adjusted for baseline score and using generalised estimating equations to account for repeated measures, and bootstrapped standard errors to account for departures from normality. Estimates were adjusted for gender, KSKS, KSFS and Charnley category as these measures were associated with the outcome in question, and groups showed some suggestion of imbalance in these variables. Estimates are presented with 95% CI and associated p-values. Data analysis was performed using Stata/IC 13.2 for Windows (StataCorp LP, College Station, Texas). A p-value < 0.05 was considered statistically significant.

Results

Of the 91 patient data sets available, kinematic graphs were classified as varus in 50 (55%), oblique in 19 (21%), neutral in 17 (18.5%) and valgus in five (5.5%).

Analysis of the demographic data for the varus and oblique groups (n = 69) showed equivalence between groups in age, BMI, ASA scores, patellar resurfacing, lateral
release and type of disease (Table I). The oblique kinematic group (group 1) had a higher percentage of females compared with the varus group (group 2) 79% versus 58% (chi-squared, p = 0.106), and more patients with Charnley classification C (p = 0.099, chi-squared test). There were no significant differences in the pre-operative KSKS and KSFS scores between the varus and oblique groups (Table II).

Table II shows the results of linear regression models of the KSKS and KSFS scores. At three months post-operatively, the unadjusted mean difference was 10.6
The growth plate.22-26 Therefore, people involved in sports retard physeal growth by compression of the medial edge of the growth plate. Thus, hip adduction moment generated whilst walking may act to retard physeal growth.22 Moreover, people involved in sports and high energy activities during the period of increased bone growth may develop constitutional varus.27 Interestingly, the demographics of the patients in Bellemans et al’s study were different to those in our study where females comprised 15 of the 19 patients (79%) vs 10 of the 50 patients (20%).

In all, two patients (10.5%) in the oblique group were dissatisfied or unsure, compared with three (6.3%) of the varus group (p = 0.261, Wilcoxon rank sum test) (Table IV).

Femoral component rotation was measured in 17 of the 19 knees with an oblique graph and 25 of the 50 knees with a varus graph. The oblique group had a mean 1° external rotation compared with 0.3° external rotation in the varus group (p = 0.204).

Discussion

We identified four distinct kinematic graphs in knees, and showed that those with an oblique graph had a significantly poorer KSKS score three months after TKA. Although this difference was attenuated by 12 months, the 95% CIs for the difference at this time ranged from -11.6 points to 1.7 points (p = 0.084) suggesting poorer outcomes for these patients.

Historically, when performing a TKA, the surgeon aimed to place the lower limb in neutral mechanical alignment. This relies on correcting the hip-knee-ankle (HKA) angle to neutral. This principle is based on studies of normal alignment and those relating mechanical alignment to the long-term survival of TKA.1,6,7,14-18 However, anatomical studies have shown that the coronal HKA alignment of the leg varies from neutral in up to 98% of patients. Eckhoff et al19 found that only four of 180 non-degenerative knees had a HKA angle of 0°, and the deviation from the neutral mechanical axis was > 3° in 76% of patients. Using standing digital radiographs, Bellemans et al20 found that 32% of men and 17% of women had constitutional varus knees with a natural mechanical alignment of > 3°. Given the anatomical findings of alignment documented in the literature, and the occurrence of different kinematic graphs noted intra-operatively in our study, it is possible that a method of aligning the components during TKA that better replicates the native anatomy and soft-tissue constraints may benefit those patients with an oblique type of kinematics.21

The underlying cause for an oblique kinematic graph needs to be fully defined. It is possible that it may represent the constitutionally varus knee, while the varus graph represents a more neutrally aligned knee that has developed a varus deformity secondary to degenerative changes in the medial compartment. Bellemans et al20 reported that a significant proportion of their patients had varus alignment once they reached skeletal maturity. They reported that the average normal alignment of the leg is not zero, but in fact slightly greater than 1° mechanical varus and with a relatively large standard deviation about the mean. Additionally, it has previously been proposed that constitutional varus may be due to Hueter-Volkmann’s law whereby the adduction moment generated whilst walking may act to retard physeal growth by compression of the medial edge of the growth plate.22-26 Therefore, people involved in sports and high energy activities during the period of increased bone growth may develop constitutional varus.27 Interestingly, the demographics of the patients in Bellemans et al’s20 study of healthy subjects were different to those in our study where females comprised 15 of the 19 patients (79%) with oblique initial kinematic graphs, whereas in Bellemans

| Table II. Descriptive statistics, adjusted and unadjusted mean difference estimates in the varus and oblique groups |
|----------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| **Varus (n = 50)** | **Oblique (n = 19)** | **Varus vs Oblique** | **Adjusted mean difference†† (95% CI)** | **p-value** | **Adjusted mean difference†* (95% CI)** | **p-value** |
| **Knee Society Score** | | | | | | |
| Pre-surgery | 38.6 | 13.9 | 43.2 | 10.9 | 4.6 (-2.5 to 11.7) | 0.197 | NA | |
| 3 mths | 82.7 | 12.7 | 72.1 | 16.2 | -10.6 (-2.5 to -18.7) | 0.011 | -9.2 (-17.8 to -0.5) | 0.038†* |
| 12 mths | 90.9 | 10.0 | 84.5 | 13.7 | -6.4 (-0.4 to -12.3) | 0.038 | -5.0 (-11.6 to 1.7) | 0.084†† |
| **Knee Society Function Score** | | | | | | |
| Pre-surgery | 53.8 | 19.0 | 48.4 | 12.4 | -5.4 (-14.8 to 4.0) | 0.258 | NA | |
| 3 mths | 68.8 | 15.3 | 57.2 | 22.4 | -11.6 (-21.9 to -1.3) | 0.027 | -3.7 (-13.2 to 5.9) | 0.452†† |
| 12 mths | 78.3 | 17.2 | 68.2 | 13.7 | -10.1 (-20.5 to 0.2) | 0.054 | -1.8 (-9.9 to 6.4) | 0.668†† |

* independent t-test
† estimates from linear regression model of three and 12 month scores with generalised estimating equations to account for repeated measures and bootstrapped standard errors to account for departures from normality
‡ missing eight cases in Varus group and three cases in Oblique group
** adjusted for pre-surgery score and gender
†† adjusted for pre-surgery score, gender and Charnley category
sd, standard deviation, CI, confidence intervals, NA, not appropriate
et al’s study males outnumbered females at a ratio of almost 2:1. The other possible explanation for the number of oblique kinematic graphs is inaccurate registration, whereby if the trans-epicondylar axis is mapped > 4° from the true axis, an oblique graph is artificially created in a standard varus knee. This is due to the fact that the plane through which the navigation unit measures this graph is perpendicular to the epicondylar axis as mapped by the surgeon. The lack of difference between the groups in femoral rotation seen on CT means it is unlikely that the altered kinematics are due to malrotation of the femoral component.

The findings on CT post-operatively in this study suggested that rotation of the femoral component did not explain the oblique kinematic graphs. Furthermore, an anatomical variant with relative hypoplasia of the posterior lat-
eral femoral condyle would also lead to a transition of varus in extension to valgus in flexion or an oblique graph. Alternatively we postulate that anteromedial tibial chondral loss would produce varus in extension, with relative valgus as the femur rolls back on the tibia during flexion.28

Both the varus and oblique (varus to valgus subtype) groups have varus alignment in extension and have medial compartment osteoarthritis. With flexion of the knee, the oblique group at least partially corrects this alignment and often overcorrects it to have a valgus alignment with the knee in 90° of flexion. Given that this is the natural soft-tissue envelope for the individual, taking that joint and correcting it to neutral alignment must conflict with its native anatomy. Once a joint replacement is inserted, it is conceivable that a conflict between the conformity of the joint and soft-tissue constraint may result in pain, reduced ROM and poorer function, or all three. Examples of pre- and post-operative graphs with corresponding radiographs are seen in Figure 2. Case 1 shows a varus knee with a varus native kinematic graph converted to a neutral graph with TKA. Case 2 shows a varus knee on an anteroposterior radiograph with an oblique native kinematic graph, converted to a neutral graph with TKA. By identifying the oblique group as a difficult set of patients who have a higher risk of poor outcome after TKA due to the unnecessary correction of the oblique kinematics to neutral, further investigation can be performed to help determine the best treatment for these patients. This group will need to be identified pre-operatively. The same may be true for mischaracterisation of patients with oblique (valgus to varus) kinematics as varus knees.

The resurgence in interest in alternative alignment options in TKA such as kinematic alignment is relevant to...
this study. The interaction between the conforming nature of the joint surface and the soft-tissue constraints has been widely discussed. Yet the manner in which one affects the other in its anatomy, pathology and following TKA has not been fully described nor understood. Dossett et al performed a double-blind, randomised control trial to determine whether kinematically aligned TKA using patient specific guides produced different alignment of the limb, knee and components than mechanically aligned TKA with conventional instruments and showed improved short-term functional outcomes in TKA with kinematic axis alignment. Others have found no difference between these two groups.

The effect of alternative ways of introducing the components in patients with oblique kinematic graphs should be further investigated. The use of a ligament balancing technique may offer benefits to this group, but ligament balancing techniques still alter the natural obliquity of the joint line and are likely to alter the kinematic graphs in a similar manner as the navigated measured resection technique used in this study. Alternatively, the use of kinematic axis knee arthroplasty, which maintains the patient’s pre-disease alignment, may confer greater benefits to this group of patients. We did not perform a sample size calculation in advance and therefore our limited sample size was probably under-powered other than to detect large group differences only. In addition, the small sample size resulted in uncertainty in the estimated differences between the groups, as evidenced by wide confidence intervals.

In conclusion, this study provides preliminary evidence of the potential for poorer outcomes in patients with an initial oblique kinematic graph than those with a varus graph. We acknowledge the limitations of this study due to its retrospective design and relatively low numbers of patients, but feel that the results justify further investigation into the effect of the native anatomy of the knee and kinematics, and a confirmation of differences in outcome in an adequately powered, prospective study.

References


