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Variable rotation of the femur does not affect outcome with patient specific alignment navigated balanced TKA

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Abstract

Purpose Excessive internal and external rotation of the femoral component has been associated with poor outcome with a measured-resection neutral mechanical alignment TKA. This technique assumes that every tibia is in 3° of varus so the femoral component is placed in 3° of external rotation relative to the posterior condylar axis to enable a balanced flexion gap. This is not the case as there is wide variability in the bony anatomy and soft tissue envelope of the knee so flexion imbalance may occur. A patient-specific alignment navigated balanced TKA technique was performed whereby the tibia is cut anatomically up to 3° of varus, then a ligament tensor is used to determine the optimal femoral component position for a balanced TKA. This results in variable femoral rotation. The hypothesis is that matching the femoral component rotation to the patient's anatomic tibial cut and soft tissue envelope will not affect clinical outcome

Methods In a single surgeon series 287 consecutive varus aligned TKA's were performed using this technique with an Attune cruciate retaining fixed bearing TKA with an anatomic patella resurfacing. The angle between the posterior femoral cuts and the posterior condylar axis was collected using Brainlab software. Functional scores were collected prospectively preoperatively and at two years. The variable femoral component rotation was correlated with and compared with the functional outcome scores.

Results The femoral rotation varied from 7° of internal rotation to 8°of external rotation relative to the posterior condylar axis. The mean rotation was 1.1° of external rotation. There was no significant difference in the Oxford score, WOMAC score, Forgotten Knee Score, KOOS Joint Replacement score or Patient Satisfaction in respect to the variable femoral rotation relative to the posterior condylar axis.

Conclusion When a more anatomic-balanced TKA technique is used variable femoral rotation will not affect clinical outcome at two years

Level of evidence II Prospective Cohort Study.

Keywords Computer assisted surgery · Total knee arthroplasty · Distal femoral rotation · Balanced TKA

Introduction

It is a well-established opinion that internal rotation of the femoral component in total knee replacement (TKA) is detrimental to patient satisfaction and clinical outcomes [16, 22, 33]. Thielemann et al. [33] also reported that excessive femoral component external rotation greater than 3° is associated with significantly poorer subjective and objective outcome. This evidence comes from measured-resection mechanical alignment TKA techniques whereby the femur and tibial are cut independently with the posterior femur cut routinely in 3° of external rotation. This is based on the premise that the tibia is in 3° of varus, so if the tibia is cut at 0°, a balanced flexion gap is achieved if the femur is cut in 3° of external rotation. However, the assumption that the tibia is always in 3° of varus is incorrect. Hirschmann et al. [17–19] recently introduced a new classification system for the overall knee alignment based on phenotypes. They showed that osteoarthritic or non-osteoarthritic knees have a huge variation in overall coronal limb alignment as well as in femoral and tibial coronal alignment.[15, 26].

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Almaawi et al. [2] showed in an analysis of 4884 CT scans that although the mean tibia was in 2.9° of varus, the range was from 20.5° of varus to 20.5° of valgus. Only 8.4% had a tibia with 3° of varus. Thus applying 3° of femoral external rotation to every knee will only provide a balanced flexion gap in a small number of patients. Inadvertently internally rotating the femoral component is likely to further increase lateral flexion instability particularly in a knee with a more varus tibia.

This is important as femoral component rotation directly influences knee kinematics by affecting its stability in flexion and the patellofemoral joint tracking [27].

For the Patient Specific Alignment (PSA) navigated balanced technique the tibia is cut anatomically up to a maximum of 3° of varus. Using a ligament tensor device the flexion gap is matched to the extension gap to enable the TKA to be balanced through a full range of motion. This results in variable rotation of the femoral component including internal rotation.

The objective is to assess patients' clinical outcomes according to the variable femoral component rotation using a PSA navigated balanced technique.

The hypothesis is that matching the femoral component rotation to the patient's anatomic tibial cut and soft tissue envelope will not affect clinical outcome.

Materials and methods

A prospective, consecutive, single surgeon case-series study on 287 consecutive varus osteoarthritic knees with two years follow-up was performed. A PSA navigated balanced technique was performed with Brainlab 3 CAS (Brainlab AG, Munich, Germany). The patient's intraoperative surgical data was recorded during the procedure including the femoral component rotation. The femoral rotation measurement used was the angle between the posterior condylar axis and the actual posterior femoral cuts made to achieve a balanced flexion gap (Fig. 1). The prosthesis implanted was the Attune (Depuy Synthes, Warsaw, IN, USA) cruciate retaining implant with a fixed polyethylene insert in all cases. Both tibial and femoral components were cemented. The patella was always resurfaced with an anatomic patella.

The Oxford score, WOMAC score, Forgotten Knee Score, KOOS Joint Replacement score and patient satisfaction were assessed preoperatively and at two years. Patient satisfaction was evaluated using a Patient Satisfaction scale from 0 to 100 (0 is completely unsatisfied while 100 is a total satisfaction). The data was collected independently with patients inputting data into an Internet-based platform with the Socrates orthopaedic outcomes system (a specific orthopaedic software programme). These scores were correlated with the femoral component rotation recorded during the surgical procedure. As the number of patients with femoral component rotation greater than 3° of internal or external rotation was small, two further analyses were performed. Firstly we compared the 16 patients who were internally rotated (> 3°IR), with the 215 neutral (3° IR—3°ER), and 56 who were externally rotated > 3°ER. Secondly, we compared the 66 patients who had an internally rotated femoral component vs the 221 patients who had neutral or externally rotated of the femoral component.

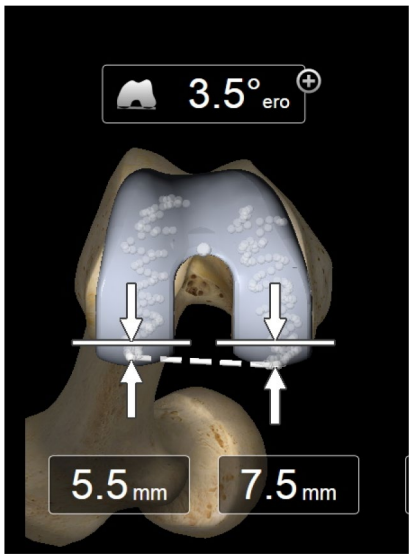

Fig. 1 Femoral component rotation. This is the angle between the posterior condylar axis and the posterior condylar resections made to have the optimal flexion gap. In this case the femoral component is rotated 3.5° externally in relation to the posterior condylar axis with 7.5 mm resected off the posterior medial femoral condyle and 5.5 mm of the posterior lateral femoral condyle

A sample size of 270 provides > 90% power to detect correlations > 0.20 between rotation and outcomes as statistically significant (2-tailed alpha = 0.05). Additionally, for the comparisons of the patient outcomes from the Internal rotation group with the other patients, allowing for the disparity in sample sizes between the groups the study had > 80% power to detect absolute differences in of greater than or equal to 2.0, 4.0, 10.0, 8.0 and 6.5 for the Oxford, WOMAC, Forgotten knee score, KOOS JR, and patient satisfaction score respectively, as statistically significant (2-tailed alpha = 0.05). These differences all represent effects that are smaller than the minimal clinically important differences for these scales therefore, the study is more than adequately powered to usefully test the effects of rotation on patient outcomes.

We also recorded if there was any lateral patellofemoral ligament release performed during the surgery. The study was approved by the New Zealand Ethics Committee. Patient consent was required for data to be collected.

Patients

All patients with a varus knee (HKA < 180°) who underwent a TKA between the 1st of May 2015 and the 11th of September 2017 who meet the inclusion criteria were included. 325 TKA's were performed over this period. 287 patients were included in this study. Four patients passed away, two had a deep infection and 32 were lost to follow-up. Thus, the follow-up rate was 90% (Fig. 2).

Patients were excluded if they had a previous osteotomy, a femoral or tibial fracture or a valgus knee. Males were slightly more prevalent at 56% while 54% had a right TKA. The mean age at surgery was 66.4 years old (38–84) and the mean pre-operative alignment was 6.7° of varus (0°–17.5°).

Surgical technique

All the patients had a PSA navigated balanced TKA [9]. A tourniquet was inflated. A medial parapatellar approach was made and the navigation trackers were positioned on the femur and tibia. The posterior cruciate ligament was preserved. The knee registration was performed. The lower limb alignment and correctability were determined. A bounded anatomic tibial cut was performed. This is determined by Howell's intraoperative method [20] whereby the medial plateau point is made at the tidemark where cartilage transitions to bone (Fig. 3). At this point 2 mm of articular cartilage is lost. The anatomic tibial cut is thus determined by 9 mm being resected off the normal lateral compartment and 7 mm being resected off the arthritic medial compartment. The resultant angle was then evaluated (Fig. 4). If there was no tidemark, an estimation is made of the amount of bone loss which is added to the calculation. The sagittal

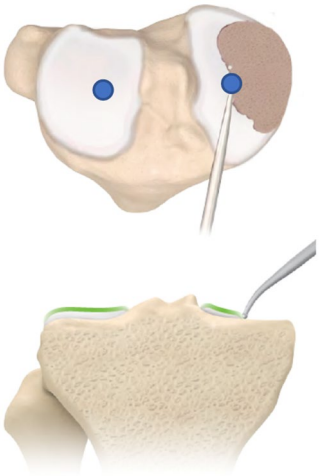

Fig. 3 The medial point is made at the tidemark where cartilage transitions to bone where 2 mm of cartilage is lost. The lateral point is made in the same anteroposterior and medial lateral position on the lateral tibial plateau

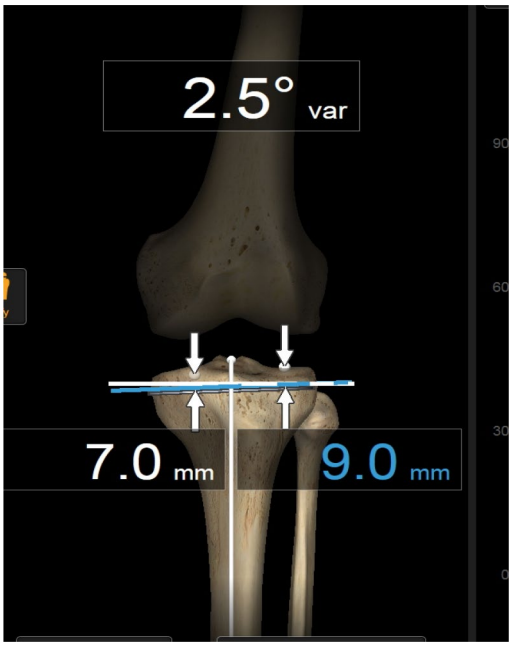

Fig. 4 An anatomical tibia cut is made when 9 mm is removed from the normal lateral tibial plateau and 7 mm is removed the arthritic medial compartment. For this patient 2.5° of varus is anatomical

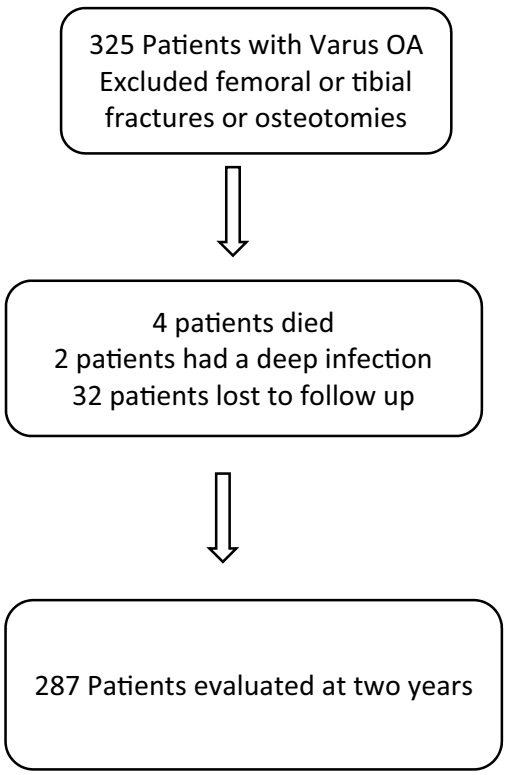

Fig. 2 Patient flow chart

tibial slope was cut at 6° as per the designer's recommendation to enable optimal kinematics for the Attune implant. If present, posterior osteophytes were removed using a curved osteotome. This step is crucial to balance the knee in flexion and extension. A ligament tensor (Fig. 5) was then inserted and the knee was placed through a full ROM in the natural and corrected position with the patella reduced. The Brainlab 3 platform produces a balance curve (Fig. 6) from which the surgeon can adjust the femoral component position to enable a balanced TKA through a full range of motion. The extension gap was balanced by altering the distal femoral cut angle, the flexion gap was altered by rotating the femoral component then finally the extension and flexion gap are balanced by changing the femoral component size and/or flexing the femoral component to reduce the flexion gap or extending and anteriorizing the femoral component to increase the flexion gap. The balance philosophy is to have the extension gap equally balanced medially and laterally while there is 1–1.5 mm more laxity in the lateral compartment in flexion to allow lateral rollback in flexion This will internally rotate the femur approximately 1° more than having an equal flexion gap The MCL should be equally tensioned through a full ROM so the medial flexion and extension gap are the same.

The overall alignment was bounded to a maximum of 3° of varus. So, if the combined planned femoral and tibial cuts are greater than 3° of varus, a medial release was performed with the tensor in place so the release can be titrated to enable a maximum of 3° of varus overall alignment. The posterior femoral condyle cuts are referenced against the posterior condylar axis. Tibial baseplate rotation was set in relation to the anteromedial cortex of the

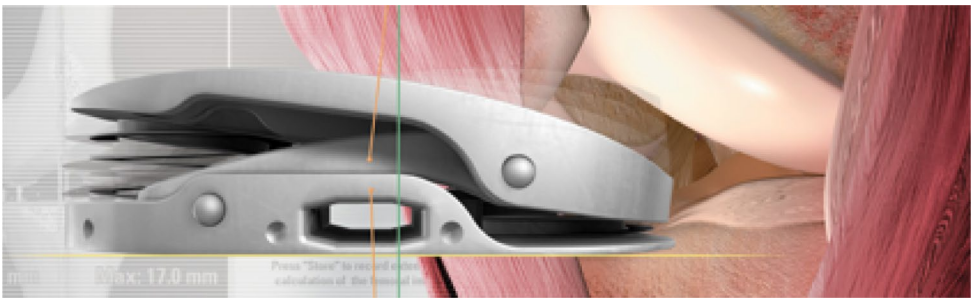

Fig. 5 The DePuy Ligament tensor used to balance the knee

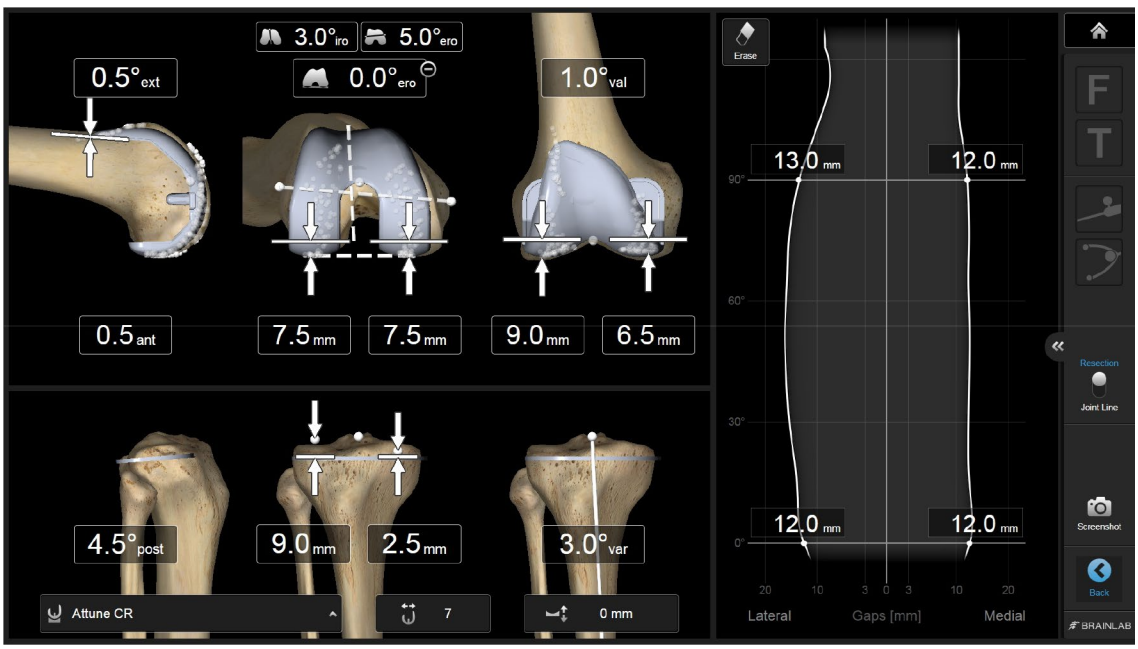

Fig. 6 Example of a Brainlab femoral planning screen with balance curve. For this patient the tibia was anatomically in 8° of varus. A bounded cut was made at 3° of varus. To balance the extension gap symmetrically the femur was cut at 1° of mechanical valgus. To balance the flexion gap with 1 mm more lateral laxity the femoral component was cut at 0° relative to the posterior condylar axis. To balance the flexion and extension gap so the MCL is equally tensioned through a full ROM the femoral component was extended 0.5° and anteriorized 0.5 mm.

tibial plateau [4]. Trials implants were inserted to confirm that the knee is well balanced and aligned. The PCL was released if the knee was tight in flexion. An anatomic patella was implanted. The patella component was rotated to match the rotation of the femoral component. This is achieved by rotating the patella trial handle to be parallel to the plug holes of the femoral trial (Fig. 7). Thus, the positioning of the anatomic patella component matches the variable rotation of the femoral component. Finally, the definitive prosthesis was implanted with Smartset cement.

Statistics

The paired *t* test was used to analyse the clinical outcome. Pearsons' correlation coefficient was calculated between the variable femoral component placement and clinical outcomes. All data were checked for normal distribution using the normality test by D'Agostino and Pearson. *p* values of less than 0.05 were considered statistically significant. All data was given as mean, standard deviation of mean and range if applicable. The ANOVA test was used to compare the internally rotated, neutral and externally rotated femoral component with each outcome score. The *T* test was used to compare the internally rotated group with the neutral and external rotation group.

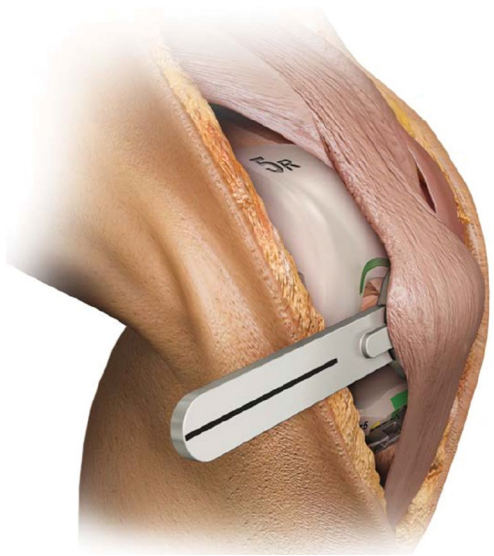

Fig. 7 The patella trial handle is rotated parallel to the trial femoral component lug holes to ensure the anatomic patella rotation matches the rotation on of the femoral component

Results

The femoral rotation varied from 7° of internal rotation to 8° of external rotation relative to the posterior condylar axis, the mean rotation was 1.1° of external rotation. Most of the patients were in the range of ± 3° from neutral rotation (215 out of 287–75%), (Fig. 8).

There was no significant correlation between the variable femoral rotation and the outcome scores (Figs. 9, 10, 11, 12,13).

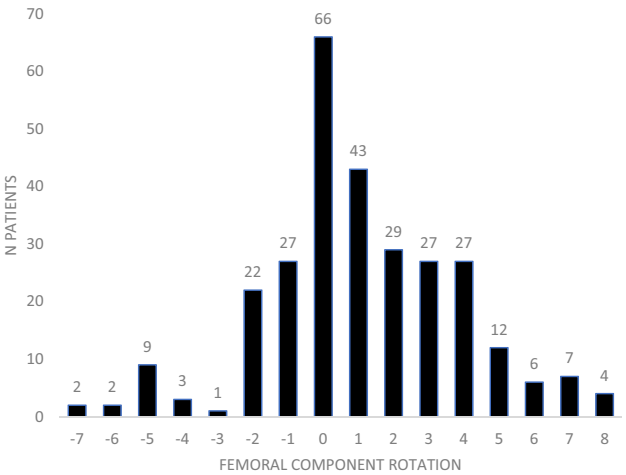

Fig. 8 Femoral Component Rotation relative to Posterior Condylar Axis. Negative values are for internal rotation angle while positive ones are for external rotation

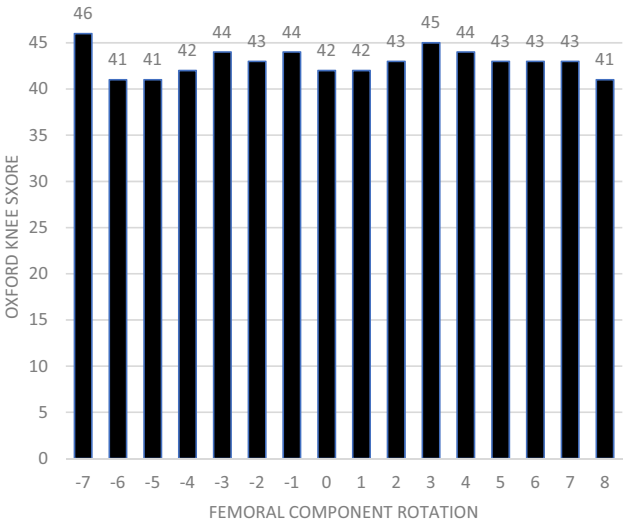

Fig. 9 Mean Oxford Knee scores related to the femoral component rotation. There was no correlation between these two variables, $r = 0.005$. $p = 0.93$

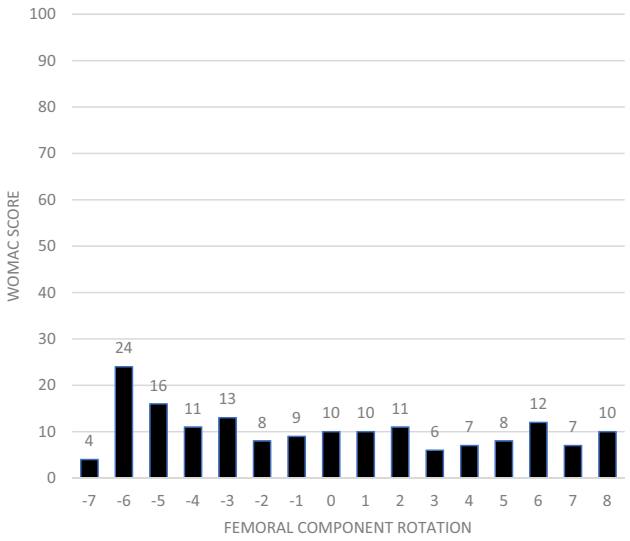

Fig. 10 Mean WOMAC score related to femoral component rotation. There was no correlation between these two variables, $r=0.007$. $p=0.91$

There was no difference in the, Oxford Score, WOMAC score, Forgotten Knee Score, KOOS JR score or Patient Satisfaction for the internally rotated group, neutral group or externally rotated group (Table 1) and the internally rotated group and the neutral and externally rotated group (Table 2).

The two year outcome scores were high with an Oxford score of 43, a WOMAC score of 9.2, Forgotten Knee score of 67.4, KOOS Jr score of 75.5 and patient satisfaction at 90.3

The mean post-operative alignment was 1.3° of varus (2° of valgus to 4° of varus). A medial release was required in 13 patients – 4.5%.

The tibia pre-operative mechanical axis ranged from 0° to 9° of varus with a mean of 2.8° of varus. The tibial plateau was cut on average at 2.5° of varus (range 0°–3°). Overall, the tibial cut was anatomic 75% of the time. If the tibia had greater than 3° of varus alignment, they were cut at 3° thus they had a non-anatomic tibial cut (Fig. 14).

The femoral mechanical axis was a mean of 1° of valgus and ranged from 4° of valgus to 3° of varus (Fig. 15).

No patient underwent a lateral release and no patient developed a patella complication in the first 2 years. Two patients had a deep infection requiring a two-stage revision. No other revisions were required, thus the two year survival was 99.3%.

Discussion

The most important finding of this study was that patient outcome and satisfaction was not altered by variable femoral component rotation when a PSA navigated balanced TKA technique was performed in varus knees. This is the first study to report this finding using an anatomically aligned balanced TKA technique.

Patient dissatisfaction after a TKA is an issue affecting approximately 20% of patients [13, 28]. Many reasons have been reported, including excessive patient expectations, persistent pain, post-operative complications and also implant malposition [12, 32]. Indeed, it has been widely published in the literature that positioning the femoral component in internal rotation is a common error that may lead to anterior pain, flexion instability, abnormal gait patterns, stiffness, patellar maltracking and could overload the medial compartment [1, 5, 7, 8, 16, 25]. All of these publications showed the negative influence of internally rotating the femoral component with a measured-resection

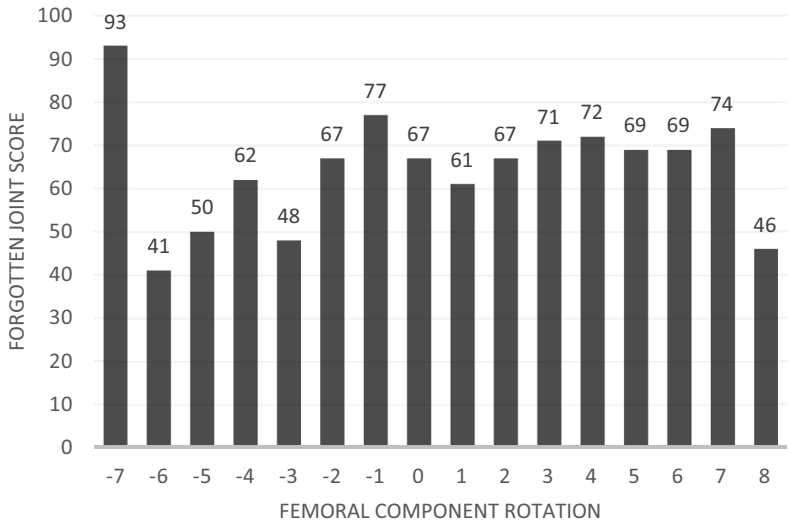

Fig. 11 Mean Forgotten Knee score related to femoral component rotation. There was no correlation between these two variables, $r=0.035$. $p=0.55$

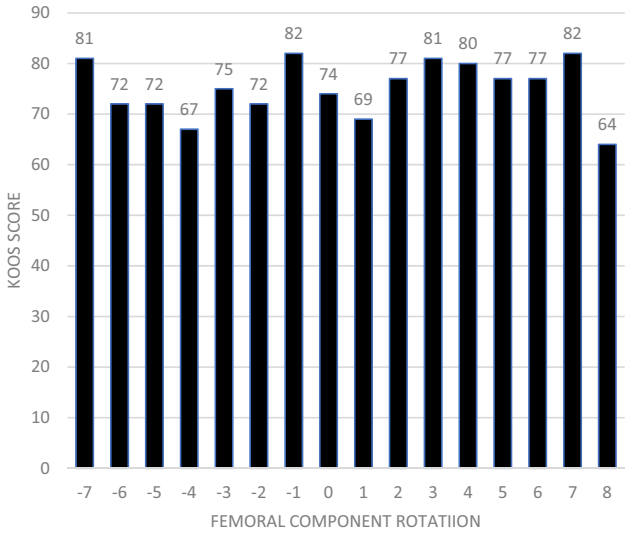

Fig. 12 Mean KOOS score related to femoral component rotation. There was no correlation between these two variables, $r=0.013$. $p=0.83$

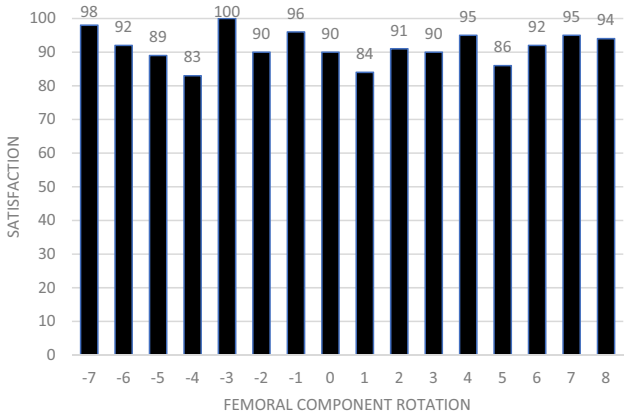

Fig. 13 Patient Satisfaction related to femoral component rotation. There was no correlation between these two variables, $r=0.025$. $p=0.67$

mechanical alignment TKA technique. This is not surprising as this technique independently cuts the femur and tibia with the assumption that the tibia is always in 3° of varus. By not linking the tibial cut to the posterior femoral cut to balance the flexion gap errors may occur. Aiming for 3° of femoral external rotation has also been shown to be not reproducible. A recent study by Becker et al. [6] has shown that a conventional measured-resection neutral alignment technique does result in variable femoral component rotation despite aiming for 3° of external rotation. They showed variation of 6.5° of internal rotation to 6.5° of external rotation.

Very few studies have assessed functional outcomes in relation to femoral component rotation.

Table 1 Outcome scores in three groups: Patients externally rotated > 3°, internally rotated > 3° and a more neutral group—3°internally rotated to 3°externally rotated

	Mean	*N*	Std. deviation	*p* value
Oxford				
ER	43.4	56	4.0	0.545
IR	41.8	16	4.6	
Neutral	43.0	215	5.7	
Total	43.0	287	5.4	
WOMAC				
ER	8.2	56	8.8	0.637
IR	10.9	16	8.6	
Neutral	9.4	215	11.5	
Total	9.2	287	10.9	
Forgotten Knee score				
ER	69.6	56	24.9	0.460
IR	60.3	16	24.4	
Neutral	67.4	215	26.7	
Total	67.4	287	26.2	
KOOS JR				
ER	78.1	56	19.3	0.475
IR	71.9	16	17.7	
Neutral	75.1	215	20.9	
Total	75.5	287	20.4	
Patient satisfaction				
ER	92.7	56	12.8	0.432
IR	89.6	16	12.7	
Neutral	89.7	215	17.6	
Total	90.3	287	15.8	

ER externally rotated, *IR* internally rotated

Table 2 Outcome scores in two groups

Score	Rotation	Mean	N	Standard deviation	*p* value
Oxford	IR	43.3	66	5.2	0.58
	N + ER	42.9	221	5.8	
WOMAC	IR	9.1	66	10.3	0.94
	N + ER	9.2	221	10.9	
Forgotten Knee score	IR	69	66	26	0.5
	N + ER	66.8	221	26.2	
KOOS JR	IR	76.1	66	19.9	0.79
	N + ER	75.4	221	20.5	
Patient satisfaction	IR	92.4	66	12.6	0.15
	N + ER	89.6	221	19.5	

Those internally rotated and those in neutral or external rotation

IR internally rotated, *ER* externally rotated, *N* neutral

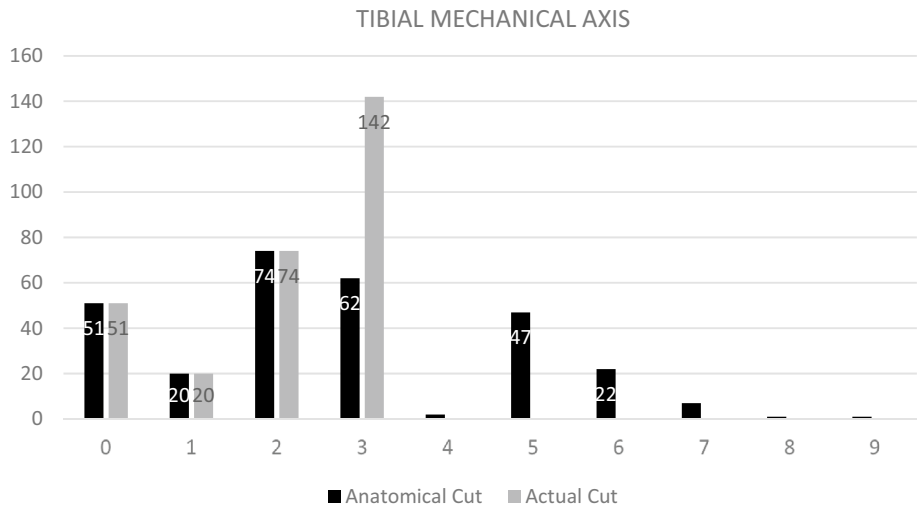

Fig. 14 Comparison of the anatomical cut and the actual cut performed. In 75% of the cases the tibial cut is anatomic. With those with a tibial mechanical axis > 3° a 3° varus cut was performed

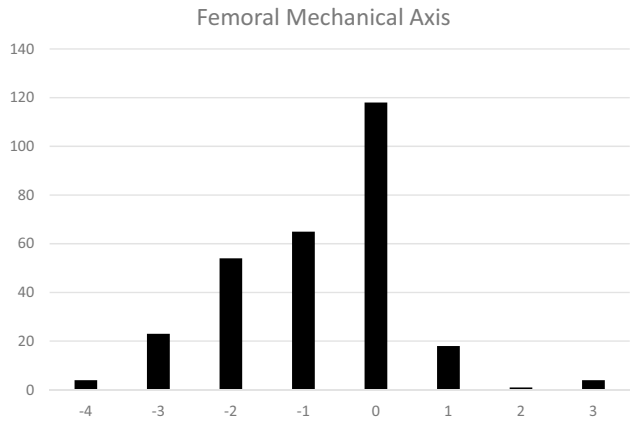

Fig. 15 Distal femoral cut values in relation to mechanical axis. Most of them were neutral (0°). Negative numbers stand for valgus cut while positive ones for varus

Kahawara et al. [22] assessed 92 knees at minimum one year follow-up and compared the knee society score (KSS) according to the femoral component rotation with a mechanical alignment technique. They showed that functional activities scores were lower in the group with internal femoral rotation than the normal rotation group ($p = 0.029$). Becker et al. [6] published that malrotation of femoral component was not associated with worse outcomes using the WOMAC and KSS in 88 consecutive patients who received a posterior stabilized TKA with measured-resection mechanical alignment at 2 years. Corona et al. [10] in a recently published systematic review combined 11 studies to show that malrotation of the femoral component in TKA does not automatically correlate to poor clinical and functional outcome.

Nedopil et al. [29] prospectively studied the impact of variable femoral and tibial rotation using a kinematic alignment technique. They assessed 71 patients at 6 months and showed a narrow range of femoral rotation from 3° of internal rotation to 2° of external rotation that didn't affect patient outcome (Oxford Knee score, WOMAC).

Several articles also highlight the fact that gap balancing TKA technique can lead to internally rotate the femoral component [11, 14, 30]. The philosophy behind a "classic gap balanced" approach (first described by Insall et al. [21]), is that the knee must be equally balanced in extension and flexion to achieve proper joint kinematics and stability. Neutral tibial and distal femoral cuts are made. If the extension gap is not balanced, soft tissues releases are performed. However, the release in extension may alter the medial structures in flexion in a variable way [23]. In 90° of flexion, a tensor is inserted to determine a balanced flexion gap. As a consequence, the rotation of the femoral component can vary freely within the restrictions of the soft tissue structures.

The PSA navigated balanced TKA technique is based on this concept of gap balancing but differs in that it aims for a more anatomic alignment of the implant with minimal soft tissue release with the aid of precise information from the navigation system [3]. The big difference is that more anatomical placement of the implants results in a much lower medial release rate which can distort normal knee kinematics.

This technique does result in more internal femoral component rotation than the classic gap balancing technique as the tibia is often cut in varus rather than neutral so more femoral internal rotation is required to balance the flexion gap and we plan for a slightly larger gap laterally in flexion to enable posterior lateral rollback of the femoral component to better replicate native kinematics. This technique is suitable for any knee phenotypes described by Hirschman.

One of the main concerns for more anatomic alignment is the more valgus position and or internal rotation of the femoral component may lead to abnormal patellar tracking and high contact stresses resulting in an increased patellar complication rate [31]. The Attune TKA has an anatomic

trochlear groove with an anatomic patellar component in comparison to some prostheses that have a single radius trochlear groove with a domed shaped patella. Moreover, the patella component is rotated to match the rotation of the femoral component. The fact that no lateral releases were performed indicates that matching the patella rotation to the trochlea groove well balances the patellofemoral joint.

There are some limitations in this study, one of the main ones is the small number of patients with greater than 3° of femoral component internal rotation (16 patients). However, 66 (22%) of cases were internally rotated which is a reasonably large number to determine whether this adversely impacts patient's outcome. No post-operative CT scan was performed to assess the femoral component rotation and confirm the peri-operative data since this is not possible as the posterior condyles which were our reference were resected. Nevertheless, CAS is a reliable tool to determine the PCA and the rotational position of the femoral component. It has been published that CAS data are very close to post-operative CT scan data [24]. Also, the short follow-up of 2 years does not enable us to evaluate the longer term survival of variable implant positioning and alignment. Patients continue to be followed prospectively so longer follow-up will be published in the future. Finally, no control group was included in this study.

These findings are relevant at a time where the wide variability in the bony anatomy and soft tissue envelope of the knee is becoming increasingly described. As a consequence many surgeons are advocating an individualized approach to total knee arthroplasty rather than the "same every time" measured-resection neutral mechanical axis technique.

Conclusion

The study showed that variable rotation of the femoral component does not affect clinical outcome and patient satisfaction at 2 years if a patient-specific alignment navigated balanced technique is used.

Funding No funding was received for this study.

Compliance with ethical standards

Conflict of interest Mark Clatworthy is consultant for Depuy. Jérôme Murgier declares no conflict of interest in relation to this article.

Ethical approval The study was approved by the New Zealand Ethics Committee.

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