Original Article

Lower limb alignment and laxity measures before, during and after total knee arthroplasty: a prospective cohort study

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Abstract

Background. This study compared knee alignment and laxity in patients before, during and after total knee arthroplasty, using methodologically similar procedures, with an aim to help inform pre-operative planning.

Methods. Eighteen male and 13 female patients were recruited, mean age 66 years (51-82) and mean body mass index of 33 (23-43). All were assessed pre- and postoperatively using a non-invasive infrared position capture system and all underwent total knee arthroplasty using a navigation system. Knee kinematic data were collected and comparisons made between preoperative clinical and intraoperative measurements for osteoarthritic knees, and between postoperative clinical and intraoperative measurements for prosthetic knees.

Findings. There was no difference in unstressed coronal mechanical femoral-tibial angles for either osteoarthritic or prosthetic knees. However, for sagittal alignment the knees were in greater extension intraoperatively (osteoarthritic 5.2° $p<0.001$, prosthetic 7.2° $p<0.001$). For osteoarthritic knees, both varus and valgus stress manoeuvres had greater angular displacements intraoperatively by a mean value of 1.5° for varus ($p=0.002$) and 1.6° for valgus ($p<0.001$). For prosthetic knees, only valgus angular displacement was greater intraoperatively (0.9°, $p=0.002$).

Interpretation. Surgeons performing total knee arthroplasties should be aware of potential differences in alignment and laxity measured under different conditions to facilitate more accurate operative planning and follow-up.

Keywords

Total knee arthroplasty, lower limb alignment, soft tissue laxity, non-invasive infrared tracking, computer assisted surgery

Introduction

Lower limb alignment in stressed and unstressed conditions are fundamental measurements in the assessment, monitoring and surgical management of patients with knee osteoarthritis. However, accurate, consistent and comparative assessment throughout the pre-, intra- and postoperative stages of total knee arthroplasty (TKA) is not currently possible due to the variety of techniques adopted. Variation between alignment and laxity measurements assessed in the clinic and the operating theatre may have implications for the surgical planning of TKA patients.

In the absence of alternative evidence, restoring the coronal mechanical femoral-tibial (MFT) angle of the lower limb to 0° (or 180°) is a common intraoperative target with a deviation beyond 3° widely associated with reduced implant survival[1-4] and poorer knee function.[5,6] However more recent controversy about the effect of knee alignment on long term TKA survivorship[7-9] has revived the debate and highlighted the importance of accurate and reproducible measurement of coronal knee alignment. In contrast to the coronal plane, sagittal alignment has been studied relatively little in the context of TKA, in spite of recognition that fixed flexion deformities or excessive recurvatum can lead to poorer functional outcomes.[10,11] Nonetheless, a generally accepted supine intraoperative target is the restoration of full passive extension.[10,12]

Soft tissues should be balanced so as to work synergistically with the knee implant and provide stability, optimal range of motion and ultimately reduce implant wear.[13,14] Varus and valgus laxity, assessed by the application of a manual stress, is a fundamental yet subjective component of many soft tissue management techniques providing qualitative evidence for intraoperative soft tissue release. Attempts have been made to categorise soft tissue laxity, such as Krackow's classification of medial ligament tightness,[15] but this assumes that all clinicians have similar examination methods and are able to reliably judge knee alignment. However, human assessment of angles is poor[16] and this has led to quantitative adjuncts such as stress radiographs[17] which, as with standard AP knee "short view" and hip-knee-ankle "long leg" radiographs, are susceptible to limb positioning errors.[18,19]

Optical tracking systems have provided surgeons with quantitative measurement tools that permit real time intraoperative assessment of knee alignment, passive range of motion and ligament laxity[20-22] to within 1° or 1mm.[23,24] As well as improving the positional accuracy of TKA implants, this technology can help to guide the extent of any surgical releases performed on restraining soft tissues in order to give a balanced knee.[25-29] Due to the requirement for bone pins to provide temporary rigid tracker fixation, it is not possible to replicate this procedure in a clinical setting. However a similar non-invasive measurement technique has been recently developed and validated by the authors, facilitating quantitative objective monitoring of static and dynamic knee alignment throughout the complete TKA process.[30-35]

The purpose of this study was to quantify lower limb alignment and coronal knee laxity pre-, intra- and postoperatively using methodologically-similar procedures. The hypothesis was that there would be no difference between alignment and laxity assessed in the clinic and intraoperatively.

Methods

This was a prospective cohort study for which ethical approval was obtained from the West of Scotland Research Ethics Committee. For an estimated effect size of 0.5, at $\alpha = 0.05$ and a power of 0.8, a sample size of approximately 30 was required for a paired t-test. Patients were approached at their pre-assessment clinics. Between May and August 2010 35 patients scheduled for TKA surgery attended the clinics. Three patients were excluded as they were not due to attend routine follow-up for geographic reasons. One patient did not speak English and so was unable to provide informed consent in the absence of an interpreter. Therefore 31 patients were approached and recruited to the study (no patients declined to be in the study). Eighteen were male and 13 female with a mean age of 66 years (range 51-82) and a mean body mass index (BMI) of 33 (range 23-43). Eighteen right knees and 13 left knees were assessed. The mean pre-operative Oxford knee score was 16, with a standard deviation of 6, and the pre-operative radiographic coronal MFT angle (as measured on long-leg film) was 2° varus with a standard deviation of 8°), ranging from 14° varus to 20° valgus. All patients had primary OA. Within the cohort five patients were morbidly obese (BMI > 40), three had lower limb lymphoedema and one with Parkinsonian tremor. All were due to undergo primary TKA by one of two consultant surgeons who routinely used the OrthoPilot® (Braun Aesculap, Tuttlingen, Germany) navigation system.

For clinical measurements, a previously validated non-invasive infrared (IR) position capture system was used. Intra-registration repeatability of this system was to 1° and inter-registration repeatability was 1.6° for coronal measures and 2.3° for sagittal measures[30]. Patients were assessed during routine preoperative and six-week postoperative clinics to quantify their lower limb alignment and knee laxity. They were positioned supine with active IR trackers non-invasively secured to the distal thigh, proximal calf and dorsum of the foot using straps and instructed to relax their leg muscles. Anatomical landmarks (femoral epicondyles and ankle malleoli) were palpated and hip, knee and ankle joint centres were located in three dimensions through a tracked sequence of clinical manoeuvres in order to determine coronal and sagittal mechanical femoro-tibial (MFT) angles. This was initially recorded with the lower limb in maximum passive extension, achieved by supporting the leg only under the heel.

Varus and valgus stress manoeuvres were then performed by applying manual force directly over the medial (valgus) or lateral (varus) ankle malleolus with the supporting hand placed over the medial (varus) or lateral (valgus) femoral epicondyle. The application was directed in the coronal plane and perpendicular to the mechanical axis of the tibia. The target sagittal MFT angle during stress testing was 2°, or 2° of flexion relative to maximum passive extension if there was a fixed flexion deformity. The magnitude of the applied stress was based on the perception of having reached a point where no further angular displacement was possible with manual load or until the patient indicated discomfort. The on-screen display of coronal angular displacement was not visible during testing to avoid operator bias and the sequence of varus-valgus stress was repeated twice. Finally, the lower limb was supported under the heel to measure coronal and sagittal MFT angles in maximum passive extension.

During TKA, the target mechanical lower limb alignment with the knee in extension was 0° in both the coronal and sagittal planes. All implants were cemented PCL-retaining condylar knee replacements (CR Columbus®, BBraun Aesculap, Tuttlingen, Germany). All but one of the knee joints were exposed using a medial parapatellar approach, the other approached laterally due to a large, fixed valgus deformity. IR trackers were secured to the distal femur and proximal tibia using bone fixation screws. Intraoperative knee alignment assessments were performed twice, on the native knee following initial surgical exposure (defined as pre-implant) and on the definitive implants after cementation (defined as post-implant), in a manner methodologically identical to the preoperative and postoperative clinical measures. The same clinician performed all clinic-based and intraoperative knee alignment measures but did not perform the TKA procedures. Statistical analysis was carried out using SPSS 17.0 (IBM Corporation, Armonk, New York). Preoperative and pre-implantation intra-operative measures were assigned as osteoarthritic (OA) data, whilst post-implant intraoperative and postoperative clinic measures were defined as the prosthetic group. Data were defined as negative for varus alignment and negative for hyperextension. For variables where more than one measurement was taken the mean value was used. Data were assessed for normality using Kolmogorov-Smirnov test and paired t-tests were used to assess changes in alignment between different measurement conditions for OA and TKA knees. Analysis was done on a complete-case basis for each measurement condition.

Results

Preoperatively there were no exclusions as non-invasive assessment was completed on all patients following recruitment. For intra-operative data collection, one patient had no data due to an error in the recording process and a second patient had no varus-valgus stress measurements due to the unavailability of the clinician to perform the manoeuvres. Post-operatively there was one case of deep infection requiring washout and exchange of the polyethylene tibial insert leading to exclusion of this patient from the trial. Therefore there were complete datasets for 31 patients pre-operatively, 29 intra-operatively and 30 post-operatively. For comparison of intra-operative and post-operative varus-valgus stress, the exclusion and missing data resulted in 28 paired measurements.

There was no statistical difference between clinical and operative measurements of unstressed coronal lower limb alignment for both OA and prosthetic knees (Table 1). However, for sagittal alignment there was a significant difference between the measurement conditions for both OA and prosthetic knees (Table 1). OA knees were in greater relative extension intraoperatively (mean -5.2°) compared to the extension seen in clinic. Prosthetic knees had an even greater tendency to more extension intraoperatively (-7.2°) compared to the relatively more flexed positions in the postoperative clinic.

For OA knees, both varus and valgus stress manoeuvres resulted in statistically greater angular displacements when performed intraoperatively (mean differences 1.5° more varus and 1.6° more valgus) compared to the clinic (Table 2). For prosthetic knees, valgus angular displacement was statistically greater intraoperatively, whereas for varus angular displacement the two conditions were not statistically different (Table 2).

Discussion

The purpose of this study was to compare clinical and operative knee alignment and laxity in patients undergoing total knee arthroplasty (TKA) to determine any differences due to measurement condition. The study showed that there was no difference in unstressed coronal mechanical femoral-tibial (MFT) angles for either OA or prosthetic knees. However, for sagittal alignment the knees were in greater extension intraoperatively. For OA knees, both varus and valgus stress manoeuvres had greater angular displacements intraoperatively whereas for prosthetic knees only valgus angular displacement was greater intraoperatively.

The fact that sagittal MFT angles were more extended intraoperatively for OA and prosthetic knees may have been due to the absence of muscle tone: in the clinical setting, muscular contraction could have potentially restricted the amount of knee extension. The removal of this muscular inhibition along with exposure of the knee possibly resulted in a more extended intraoperative position. Therefore, in spite of surgically correcting the pre-operative fixed flexion contractures to close to 0° intraoperatively, at the six week postoperative stage most patients were unable to achieve this degree of extension in the clinical setting, with the mean postoperative maximum extension only 1° more extended than the preoperative osteoarthritic measurement. This supports the widely-held belief that preoperative range of motion prior to TKA surgery is a major determinant of postoperative movement regardless of the degree of passive knee motion achieved intraoperatively.[36,37] The correction of preoperative fixed flexion deformities may therefore require release beyond a sagittal MFT angle of 0° to account for the tendency for the knee to adopt a more flexed position postoperatively. However, it is possible that flexion deformities at six weeks following TKA would improve over time as reported in previous studies[38,39] and so this requires longer follow up using this IR measurement technique. Until then, and in the absence of alternative evidence, the intraoperative target for flexion deformities should be correction to 0° with an emphasis on extension exercises in the early postoperative period.

For OA knees, varus and valgus angular displacements were statistically greater intraoperatively in comparison to the clinic setting. During preoperative clinical assessment, the limiting factor during stress testing was often the discomfort of the manoeuvre rather than the perception of a definitive end-point. Furthermore, muscular inhibition during stress testing was absent intraoperatively. Together with the effect of an open incision, we hypothesise that these differences resulted in 1.5° less angular displacement than would be expected intraoperatively for both varus and valgus stress manoeuvres. Since coronal angular displacement can form the basis of decision-making algorithms regarding soft tissue release during TKA surgery,[25-29] our results indicate that preoperative assessment is likely to underestimate the degree of intraoperative varus and valgus angular displacements by an average of approximately 1.5°. Following TKA, the valgus stress angulation was greater intraoperatively than in the clinic, whereas for varus angular displacement there was no significant difference between clinical and operative conditions. This may be due to differences in pain between varus and valgus stress manoeuvres, the latter placing strain on the more surgically traumatised medial tissues for the majority of knees. In addition, we hypothesise that contracture of the medial parapatellar wound as part of the normal healing process[40] may have added an additional restraint to valgus angulation of the knee.

The above arguments are also borne out with regards to the correlation coefficients between clinical and operative measures, pre and post TKA (Tables 1 and 2). Reassuringly, the correlations between clinical and operative measures was high prior to TKA, demonstrating reliability between the measures. Post TKA, the MFTA correlations decrease, reflecting the fact that, for coronal measures, the standard deviations are approaching the level of the repeatability of the measures, and for sagittal measures, the reappearance of flexion contracture postoperatively, irrespective of correcting to neutral alignment intraoperatively. With regards to the correlations under varus and valgus stress, the observed correlations may low due to the arguments above regarding pain, muscular inhibition and open-incisions.

We believe this is the first time that lower limb alignment has been quantified and followed through the TKA assessment and procedure using the same infrared tracking technology; the one difference in methodology being the attachment of the active trackers. In spite of the potential challenges to the registration process presented by the patient cohort, all subjects were successfully evaluated in the clinical setting with repeatable kinematic measurements providing further evidence for the effectiveness and stability of the tracker straps. Continued use of this IR system on a larger patient cohort over a longer period of time may further enhance our understanding of the relationship between intraoperative and clinical knee kinematics.

Surgeons performing TKA surgery should be aware of the potential differences in alignment and laxity measured under different conditions and to adjust their aims accordingly. A coronal deformity that is fixed or only partially corrects with manual load in the preoperative clinic may fully correct on the operating table and therefore may influence choice of surgical approach or extent of soft tissue release performed. Intraoperatively, a knee that feels "tight" in the coronal plane is unlikely to become more lax over the first six weeks, whereas a knee that feels "loose" may well "tighten" over this same period. Nevertheless, appropriate ligament balancing should be performed intra-operatively and surgeons should not rely on postoperative tightening to achieve their surgical stability aim. In the sagittal plane, intraoperative correction of fixed flexion deformities to 0° may not be enough to overcome the tendency of the knee to adopt the preoperative flexed position. Failure to achieve full passive extension intraoperatively seems unlikely to result in a knee that will "stretch out" to 0° over the first six weeks post-surgery. These are fundamental considerations for the planning and follow-up of TKA patients and may influence the long term function and survival of implants.

In spite of this study having the potential to change clinical practice, there were several methodological limitations which may restrict the wider adoption of its findings. Whilst the surgical and clinical systems were the same make and model, marker fixation differences existed. The intra-operative accuracy and repeatability of the operative measures would potentially be better than the clinical measures, due to bone fixation of the markers: soft tissue movement has the potential to introduce unquantifiable error into the clinical measures. This may not be an issue, however, since the standard deviations of the measures, which would include inter-subject variation together with other experimental errors, are essentially equivalent for clinical and operative measures, suggesting that marker fixation difference did not manifest in heterogeneous error between the groups. Additionally, the varus and valgus stress measurements were performed by a single observer with no standardisation of the applied load. Therefore, it is possible that different angular displacements would have been achieved by other clinicians, although previous work has shown a high level of inter-observer agreement for this type of manoeuvre.[31] The majority of OA knees evaluated were varus aligned, which limits the application of our findings to valgus knees, particularly with larger deformities. The follow-up period of six weeks is likely to be too early to make an assessment of long-term laxity, but nonetheless provides important and previously unreported information on knee behaviour at this post-operative stage.

Conclusions

This study has highlighted the dynamic nature of lower limb alignment and the potential variation in soft tissue envelope laxity based on the condition in which it is evaluated. Surgeons performing TKA surgery should be aware of the potential differences in alignment and laxity measured under different conditions and to adjust their aims accordingly. Continued use of the novel IR tracking technology used in this study may enhance our understanding of knee kinematics and could provide a new avenue for progress in the field of arthroplasty.

Conflicting interests

JVC was employed to carry out this work by the Golden Jubilee National Hospital using a grant from BBraun Aesculap. FP has licences and patents with BBraun Aesculap.

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		OA (n=31)	Prosthetic (n=29)
Supine coronal MFT angle (°)	**Clinical**	-2.5 (5.7)	-0.7 (1.4)
	Operative	-2.0 (5.7)	-0.2 (1.1)
	Difference	0.5 (2.8)	0.5 (1.4)
	p value	0.3	0.08
	r	0.88	0.36
Supine sagittal MFT angle (°)	**Clinical**	7.7 (7.1)	6.7 (5.1)
	Operative	2.5 (7.7)	-0.5 (3.3)
	Difference	-5.2 (4.3)	-7.2 (4.7)
	p value	<0.001	<0.001
	r	0.83	0.44

Table 1: Comparison of clinical and operative unstressed alignment for OA and prosthetic patient groups. Values are groups means with the SD in brackets. Negative values indicate varus in coronal plane and hyperextension in sagittal plane. r values are Pearson correlation coefficients between the clinical and operative measures.

		OA (n=30)	Prosthetic (n=28)
Varus angular displacement (°)	**Clinical**	-3.8 (1.5)	-4.3 (1.1)
	Operative	-5.3 (2.2)	-4.1 (1.4)
	Difference	-1.5 (2.4)	0.3 (1.4)
	p value	0.002	0.3
	r	0.20	0.36
Valgus angular displacement (°)	**Clinical**	3.3 (1.6)	2.8 (0.8)
	Operative	5.0 (1.6)	3.7 (1.3)
	Difference	1.6 (1.6)	0.9 (1.3)
	p value	<0.001	0.002
	r	0.51	0.24

Table 2: Comparison of clinical and operative coronal laxity for OA and TKA patient groups. Angular displacement is from unstressed resting position. Values are groups means with the SD in brackets. r values are Pearson correlation coefficients between the clinical and operative measures.