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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.

1. 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 (Bargren et al., 1983; Jeffrey et al., 1991; Lotke and Ecker, 1977; Ritter et al., 1994) and poorer knee function (Oswald et al., 1993; Wasielewski et al., 1994). However more recent controversy about the effect of knee alignment on long term TKA survivorship (Abdel et al., 2014; Bonner et al., 2011; Parratte et al., 2010) 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 (Goudie et al., 2011; Ritter et al., 2007). Nonetheless, a generally accepted supine intraoperative target is the restoration of full passive extension (Bellemans et al., 2006; Ritter et al., 2007).

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 (Freeman et al., 1986; Mihalko et al., 2009). 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 (Krackow, 1990), 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 (Edwards

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et al., 2004) and this has led to quantitative adjuncts such as stress radiographs (LaPrade et al., 2008) which, as with standard AP knee "short view" and hip-knee-ankle "long leg" radiographs, are susceptible to limb positioning errors (Lonner et al., 1996; Swanson et al., 2000).

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 (Bathis et al., 2004; Chauhan et al., 2004; Stulberg et al., 2002) to within 1° or 1 mm (Haaker et al., 2005; Stockl et al., 2004). 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 (Hakki et al., 2009; Jenny et al., 2004; Picard et al., 2007; Saragaglia et al., 2006; Unitt et al., 2008). 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 (Clarke et al., 2012a, b; Russell et al., 2013, 2014a, b, c).

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.

2. 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 (Clarke et al., 2012a). 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.

3. 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)