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Title: Reduced bearing excursion after mobile bearing unicompartmental knee replacement is associated with poor functional outcome.

Article Type: Original Article

Keywords: kinematics, mobile bearing, unicompartmental knee replacement, Oxford Knee Score

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Abstract: Background: A small proportion of patients with Mobile unicompartmental knee replacement (UKR) report poor functional outcomes in spite of optimal component alignment on post-operative radiographs. The purpose of this study was to assess if there was a correlation between functional outcome and knee kinematics.
Methods: From a cohort of consecutive cases of 150 Oxford medial UKR, patients with fair/poor functional outcome at one year post surgery (OKS < 34, n=15) were identified and matched for age, sex, pre-operative clinical scores, and follow-up period with a cohort of patients with good/excellent outcome (OKS ≥34, n=15). In vivo kinematic assessment was done using step-up and deep knee bend exercises under fluoroscopic imaging. The fluoroscopic videos were analyzed using MATLAB software to measure the variation in time taken to complete the exercises, Patellar Tendon Angle (PTA) and Bearing Position (BP) with Knee Flexion Angle (KFA).
Results: Mean OKS in the fair/poor group was 29.9 and the mean OKS in the good/excellent group was 41.1. The tibial slope, time taken to complete the exercises and the PTA trend over the flexion range was similar in both the groups; however, BP as well as extent of bearing excursion differed significantly. The total bearing excursion in the OKS<34 group was significantly smaller than the OKS≥34 group (35%). Furthermore, on average the bearing was positioned 1.7 mm more posterior on the tibia in the OKS<34 group.
Conclusion: This study provides evidence that abnormal knee kinematics, in particular bearing excursion and positioning, are associated with worse functional outcome after mobile UKR.

*Title Page (with full author details)

Reduced bearing excursion after mobile bearing unicompartmental knee replacement is associated with poor functional outcome.

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***Abstract (Structured; 250 Words Maximum)**

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Keywords – kinematics, mobile bearing, unicompartmental knee replacement, Oxford Knee Score.

Introduction

Unicompartmental Knee Replacement (UKR) replaces only one compartment of the knee (most commonly medial tibio-femoral) which is affected by arthritis and at the same time preserves the native ligaments and soft tissue stabilizers of the knee joint. Studies reported in the literature show high survivorship and excellent long-term results following this procedure [1]. UKR is a ligament preserving surgery with both the cruciates being retained and no ligament release performed. This contributes to better clinical outcomes and near normal knee kinematics after UKR as compared to Total Knee Replacement (TKR) [2,3].

Kinematics is the study of geometry of motion without consideration of the forces causing this motion. The kinematic analysis of knee motion is complex and involves numerous inter-related variables. To help describe the complex function of the knee mechanism as a whole, rather than the rotations and translations in isolation, alternative markers of knee movement have been studied. Two such commonly used markers are tibio-femoral contact point, and patellar tendon angle (PTA). Both of these parameters are commonly used and well validated in the literature [4,5]. The relationship between PTA and Knee Flexion Angle (KFA) has been termed the kinematic profile of the knee [6]. X-ray fluoroscopy, Magnetic Resonance Imaging and Roentgen Stereophotogrammetric Analysis (RSA) can be used to study knee kinematics. X-ray fluoroscopy is most commonly used because of its ease, ready availability, low radiation exposure and reproducibility [7,8].

Various clinical scoring systems are used to assess patient outcome after a knee replacement. Patient reported outcome measures (PROMs) are being increasingly used as they provide quantitative representation of the patient's perspective rather than a surgeon's interpretation of clinical outcome. The Oxford Knee Score (OKS) is one such tool [9,10]; it has 12 questions with a score range from 0 to 48. The OKS is easy to use, has been validated and the outcome is classified into poor (OKS <27), fair (OKS 27-33), Good (OKS 34-40) and excellent (OKS ≥ 41) [11]. After UKR the OKS typically improves within the first 6-12 months and tends to plateau after one year [12].

No studies have attempted to correlate the knee kinematics with functional outcome after UKR. The purpose of this study is to compare kinematics of two cohorts of Oxford mobile bearing medial UKR under in vivo, weight-bearing conditions during functional activities:

one with good / excellent functional outcome and the other with poor / fair clinical outcome as determined by OKS at one-year follow-up.

Methods

Ethical clearance was obtained from institutional ethical committee before the start of the study. A total of 150 knees in 84 consecutive patients underwent Oxford mobile bearing medial UKR at a single center from January 2014 to November 2015. The surgeries were performed by a single surgeon using the recommended surgical technique and a standardized post-operative physiotherapy protocol was employed for all the cases [13]. The surgical technique does not depend on the pre-operative deformity. None of the patients had varus > 15^0 or flexion deformity > 15^0 deformity.

Patients were assessed at 6 weeks and one-year post-surgery. Routine clinical assessment was performed and any complications encountered were carefully recorded. At one-year post-surgery patients completed the OKS questionnaire. This was a retrospective review of prospectively collected data.

The mean OKS at one-year follow-up for the entire cohort was 39.5 (range 11-48, SD 5.67). There were 19 cases (13%) with OKS < 34 (study group). All these patients were invited to participate in the study; 4 out of these 19 were unable to perform the requisite exercises (details of the exercises provided below) for assessment of in vivo kinematics and hence were excluded, resulting in a cohort size of 15. A sample size of 15 was deemed sufficient to distinguish between the groups. The mean OKS in this cohort (n=15) was 29.9 (range 22-33, SD 2.9). These 15 cases were matched for age, sex, pre-operative OKS and follow-up period (Table 1) with 15 patients having good or excellent OKS (OKS ≥ 34, control group). The mean OKS in this cohort was 41 (range 36-45, SD 2.7). There were 131 knees with OKS ≥ 34. From this cohort, patients living within a 15 km radius were identified (n = 56) to minimize travel time for the patients. Patients were then matched for age (± 3 years), gender, and pre-op OKS (± 4). This provided a cohort of 22 patients. All were contacted and invited to be recruited in the study. Five refused to participate in the study and two could not complete the exercises due to associated co-morbidities giving a cohort of 15 knees (15 patients).

X-ray fluoroscopic analysis for assessment of in vivo sagittal plane kinematics was carried out for all the patients in both groups. Post-operative posterior tibial slope along with alignment of the implants in both coronal and sagittal plane was also calculated for both the groups using AP and lateral X-ray radiographs for all the patients and these were compared using unpaired t-test.

Fluoroscopic data acquisition

A standardized fluoroscopic technique was used for obtaining the kinematic data [14]. Patients performed two exercises: step up and deep knee bend. These exercises were recorded under fluoroscopy (at the rate of 20 frames per second). Prior to start of the kinematic assessment, fluoroscopic axes views of the femur and the tibia were obtained. These comprised exposures of the distal half of the femur and the proximal half of the tibia of the knee under investigation. The views were subsequently used as a baseline in order to define the femoral and tibial axes. The femoral axis was defined in the manner recommended by Rees et al [15], by using the posterior border of the lower femoral diaphysis. The tibial axis (axis along the length of the tibia) was defined in a similar manner by using the posterior border of the upper tibial diaphysis.

- Step up – on a 25 cm high platform with knee flexed at approximately 70 degrees at start.
- Deep knee bend - maximal active flexion of the knee with the foot over a 25 cm high platform.

A bi-planar calibration grid (acquired with permission from the Oxford Orthopaedic Engineering Centre, University of Oxford, U.K.) having radio-opaque markers was imaged prior to each exercise to take into account the distortions and magnifications of individual X-ray frames [16].

Kinematic assessment

MATLAB software (version 7.10.0.499; R2010a) was used to analyse the fluoroscopic videos. The software enabled the calculation of the Patellar Tendon Angle (PTA), Knee Flexion Angle (KFA) and Bearing Position (BP) (tibiofemoral contact point). PTA is the angle between the long axis of patellar tendon and the long axis of tibia [5] (Fig 1); the KFA is the angle between the long axis of femur and the long axis of tibia [16] (Fig 1) and the BP is the position of the centre of articular surface of the polyethylene mobile bearing relative to the midpoint of the tibial tray keel (Fig 2). The bearing is radiolucent so the measurement of the movement of the centre of femoral component (perpendicular from the centre of femoral component to the tibial tray) relative to the position of keel (tibial tray) through the arc of flexion indirectly estimates the movement of tibio-femoral contact point in the para sagittal plane. The position of the bearing is determined in millimetres by determining the image magnification from the known size of the femoral implant. The movement anterior to the centre of the keel is taken as positive and posterior to it is taken as negative. The values of PTA were interpolated to give values for every 10^0 of KFA throughout the flexion arc in both the exercises.

Statistical analysis

To identify the required sample size to distinguish between the groups, two power analyses were performed: one for PTA, and one for BP and the larger sample size chosen for the study. Previous studies have shown PTA can be measured with a standard deviation of 3.3 degrees using an equivalent methodology [3]. Based on a power of 0.5 and 5% significance, a sample size of 11 was calculated for each group to distinguish PTA where the clinically significant difference is 4^0. Similarly, BP can be measured with a standard deviation of 1.9 mm [7], with a power of 0.5, 5% significance, and a clinically significant difference of 2 mm, a sample size of 15 was calculated for each group.

Statistical differences in the demographic data for the two groups were determined using an unpaired Student's t-test to compare age and OKS scores, and Fisher's test to compare sex. Kinematic results were compared every 10^0 (0^0 to 120^0) of KFA, where a Mann Whitney U was used to test for differences between the groups in terms of PTA and BP.

Results

An almost linear relationship was observed between PTA and KFA for both the groups for both the exercises (Fig 3). The PTA value decreased with knee flexion from almost 20˚ at full extension to minus 5^0 at 120^0 of flexion. The average PTA of OKS<34 group was 0.8^0 less that of OKS≥34 group at all the angles of KFA; however, this difference was not statistically significant ($p = 0.75$).

The movement of the bearing in both groups followed a similar trend, with movement in an anterior direction with increasing knee flexion until 80^0 and then posterior during deep knee bend (Fig 4). However, the contact point in the OKS<34 group was 1.7 mm posterior on average (from 20^0 to 90^0 of flexion) compared to the OKS≥34 group, and the difference was statistically significant ($p = 0.015$) when analyzed. The greatest difference between the groups was observed between 30^0 and 80^0 of flexion. Furthermore, the total excursion of the meniscal bearing in the OKS<34 group (2.86 mm) was significantly less than that in the OKS≥34 group (4.4 mm).

Discussion

Restoration of normal knee function after knee replacement can be expected to provide a joint that has superior functional outcome as well as excellent long-term implant survival [17], though this is not always the case. Many studies comparing knee kinematics of knee prostheses designs (different types of UKR or UKR compared with TKR or different types of TKR) have demonstrated different knee kinematics [3,10,14,16]; however, none of the studies have shown clinical or functional outcome is related to knee kinematics. This is the first study to show that the knee kinematics of mobile bearing UKR, in particular bearing excursion, is significantly associated with functional outcome.

Bearing movement analysis in UKR shows how the prosthesis components are loaded and relates to movement of tibio-femoral contact point [3]. The surgical technique for the Oxford UKR is very clear on femoral component position, it is referenced from the intramedullary canal and the spherical femoral component geometry is forgiving for malalignment. Consequently, our hypothesis is that any variation in bearing position does not relate to surgical technique, but that the position of tibio-femoral contact after Oxford UKR is predominantly dependent on ligament function [8] and muscle action [18]. Abnormal tibio-femoral movement is often cited as a cause of polyethylene wear and subsequent failure of total knee prosthesis [19]. The results of this study demonstrated a reduction in bearing excursion and posterior bearing positioning in patients with poor functional outcome, though no difference in PTA.

PTA provides indirect information about the relative position of tibia and femur and one would expect the PTA to be reduced (particularly between 30^0 - 40° of knee flexion [7]) if the knee was ACL deficient. The results therefore indicate a functional ACL, and the surgeon documented the ACL status carefully during surgery and in all cases the ACL was intact which supports this finding. Similarly, there was no significant difference in the posterior tibial slope (Table 1) or any other demographic or surgical parameters which could explain differences between the bearing movement between the two groups.

One possible explanation for the difference observed in bearing excursion is muscle action; patients may be altering their movements due to pain, or there could be a difference in muscle strength. It is also possible that impingement of the bearing by scar tissue (arthrofibrosis), retained osteophyte / cement could have contributed to limited bearing excursion. The surgeons took the necessary steps to ensure that all possible causes of impingement were addressed during surgery. Assessment of post-operative radiographs did not show presence of retained cement or osteophyte in any of the cases in either groups. As this is a cross-sectional study, it only confirms the correlation between restricted bearing movement and sub-optimal functional outcome, and not the causality.

This study has examined the knee kinematics of mobile bearing Oxford UKR in the Indian population, whereas all other published kinematic studies have been in the European population [3,20]. The approximately linear variation of PTA with KFA observed in this study correlates well with previously published work; however, there are differences in the magnitude of PTA. In the study by Pandit et al. [3] the PTA for ACLI (ACL intact) patients ranged from 14 degrees from full extension to -9 degrees at 130 degrees of flexion. In our analysis, the PTA for OKS≥34 group ranged from 19.2 degrees to -4.4 degrees for the same range of knee flexion. The bearing movement also followed a similar trend to other studies, where the bearing moved posteriorly at increasing knee flexion during the deep knee bend exercise reflecting the normal femoral roll back which is the function of intact posterior cruciate ligament. However, in the study by Pandit et al., the bearing moved from 7 mm posterior at full extension to 2 mm posterior at maximum flexion and reached midline at 80 degrees of knee flexion, while in the present study it moved from 2 mm posterior to 5 mm posterior and never reached the midline.

There are a few limitations of the study. The use of video fluoroscopy in this study provided two-dimensional images of the sagittal plane of the knee at high frame rates, but threedimensional knee movements, such as external rotation, cannot be accounted for. Although rotation of tibia in flexion can affect the tibio-femoral contact point, we ensured that the set up and the exercises were standardized. A footprint was drawn on the wooden step which patient used as a reference to place their foot on before starting the exercise. The radiographers and researchers ensured that the leg was not rotated prior to starting the exercise and the fluoroscopy set up was parallel to the leg to be examined. Freeman *et al.* [21] examined sagittal views of the knee at different degrees of flexion and found the medial compartment in the natural joint has negligible (+/- 1.5 mm) anterior-posterior excursion. However, after mobile bearing Oxford UKR the medial compartment demonstrates greater translation and may have a greater sensitivity to external rotation. Thus variation in external rotation may also be an explanation for some of the differences observed in bearing excursion.

The sample size of 15 in each group was relatively small, though sufficient to detect a significant difference in the bearing excursion and positioning. Due to the limited field of view of the fluoroscopy it was necessary to calculate the knee flexion angles using just the proximal tibia and distal femur which cannot account for diaphyseal deformity and may have introduced some error; based on the work by Rees *et al.* [6] this error would have been limited to 1 to 2 degrees. We also did ensure that distal half femoral diaphysis and proximal half of tibial diaphysis was captured at the start of the kinematic analysis to minimize the error introduced by limited field of fluoroscopic view.

It would have been preferable to be able to report more long term clinical data (functional outcomes and survivorship); however, the Oxford Knee Score has been shown to typically plateau at one year [12] so it is an appropriate time period. The patients were well matched in both the groups for all known confounding variables at one-year post-surgery, and the study examines prospectively collected data thereby removing the recall bias. It was not possible to completely eliminate selection bias from this study due to the numerous factors which can contribute to poor OKS scores. OKS is a commonly used metric and so any selection bias represents clinical practice, but future studies using more specific indicators may help to identify the underlying cause of our findings. In addition, as a matter of convenience, patients living within a 15 km radius were invited to participate in the control group. Some patients did not wish to be recruited in the study. This meant that inadvertently we might have introduced a selection bias.

Although this study has shown that the contact point was more posterior with limited excursion of the bearing in the patient group with OKS < 34, is unlikely that the posterior positioning of the contact point in the OKS<34 patients is related to the surgical technique, although not impossible. Also, it is difficult to recommend any particular surgical steps to overcome such a problem even if it is diagnosed intra-operatively. From the observation it is impossible to know whether the relationship is cause or effect. Every effort should be made during surgery to ensure that no mechanical factors contribute to restricted bearing movement i.e. removal of all possible sources of impingement but the relative position of the bearing on the tibial tray is primarily determined by soft tissues around the knee and loading patterns which indeed vary from patient to patient.

Conclusion

This study has demonstrated a significant correlation between abnormal knee kinematics and functional outcome following a mobile bearing unicompartmental knee replacement. The bearing position in patients with an Oxford Knee Score less than 34 was significantly more posterior on the tibia, and had a reduced range of bearing movement, compared to patients with an Oxford Knee Score greater than 34. Although a causal association could not be established and the clinical relevance of such differences in bearing position needs to be further evaluated, these findings provide insight into the potential reasons and indicators of poor outcome after mobile UKR surgery.

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Figure 1
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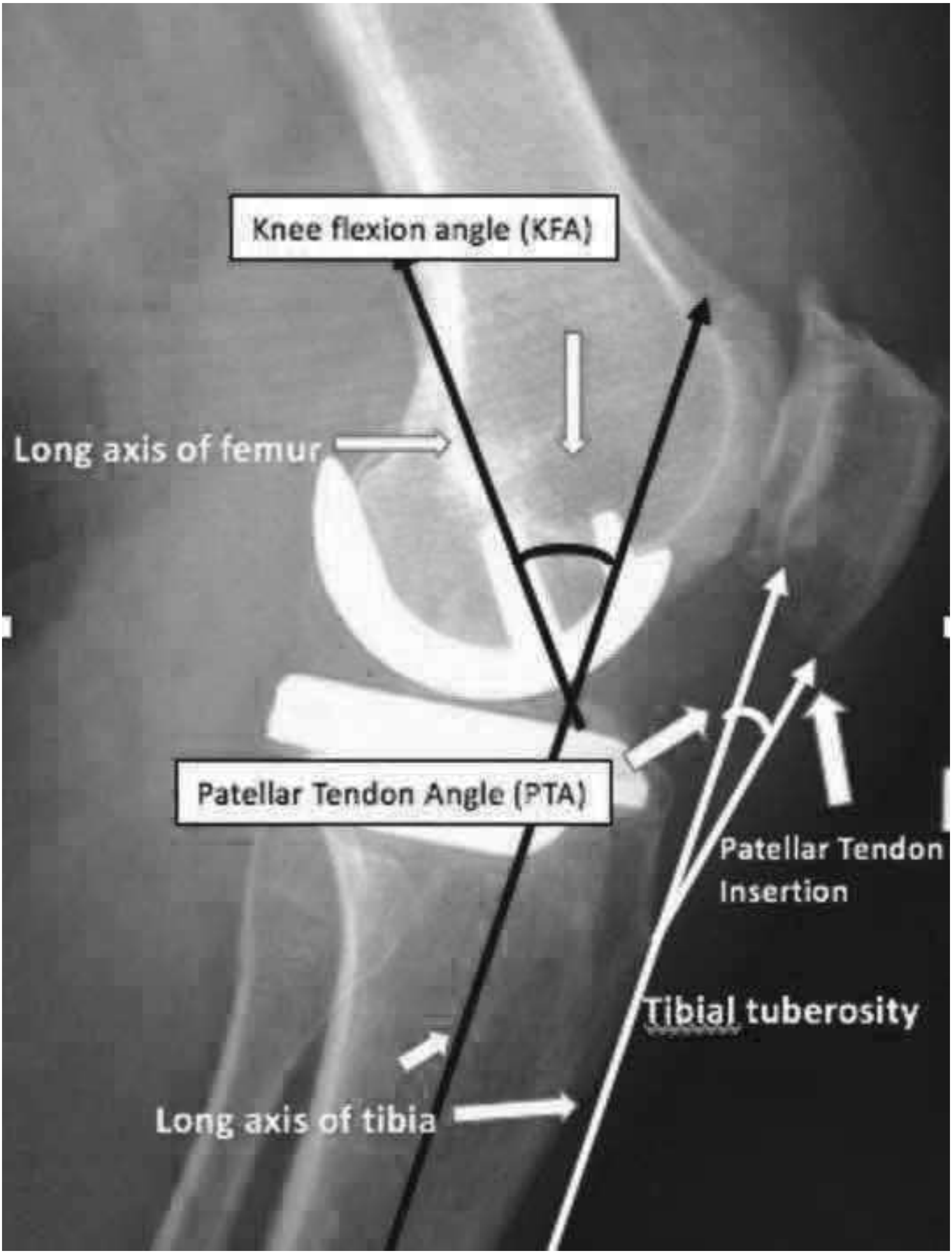

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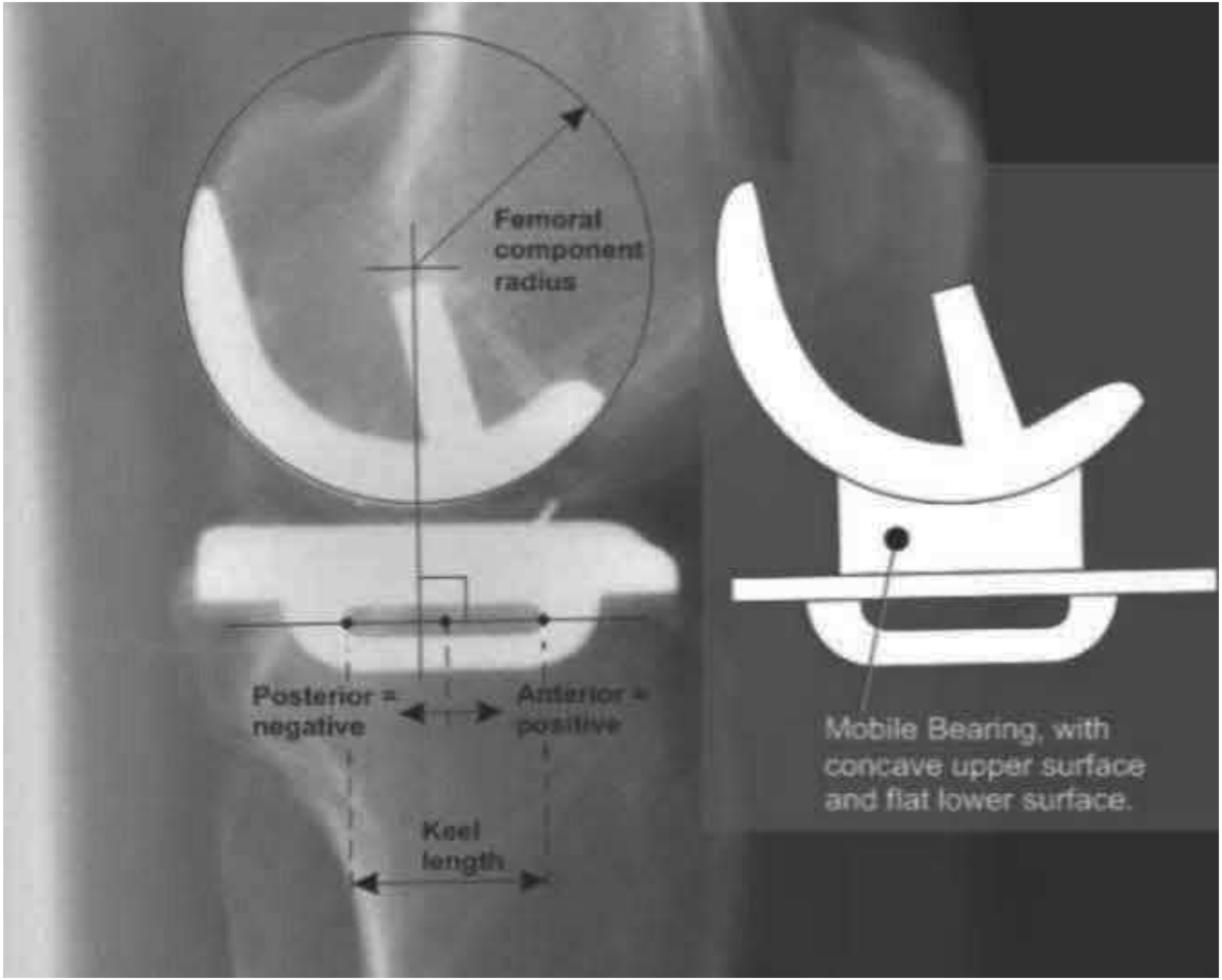

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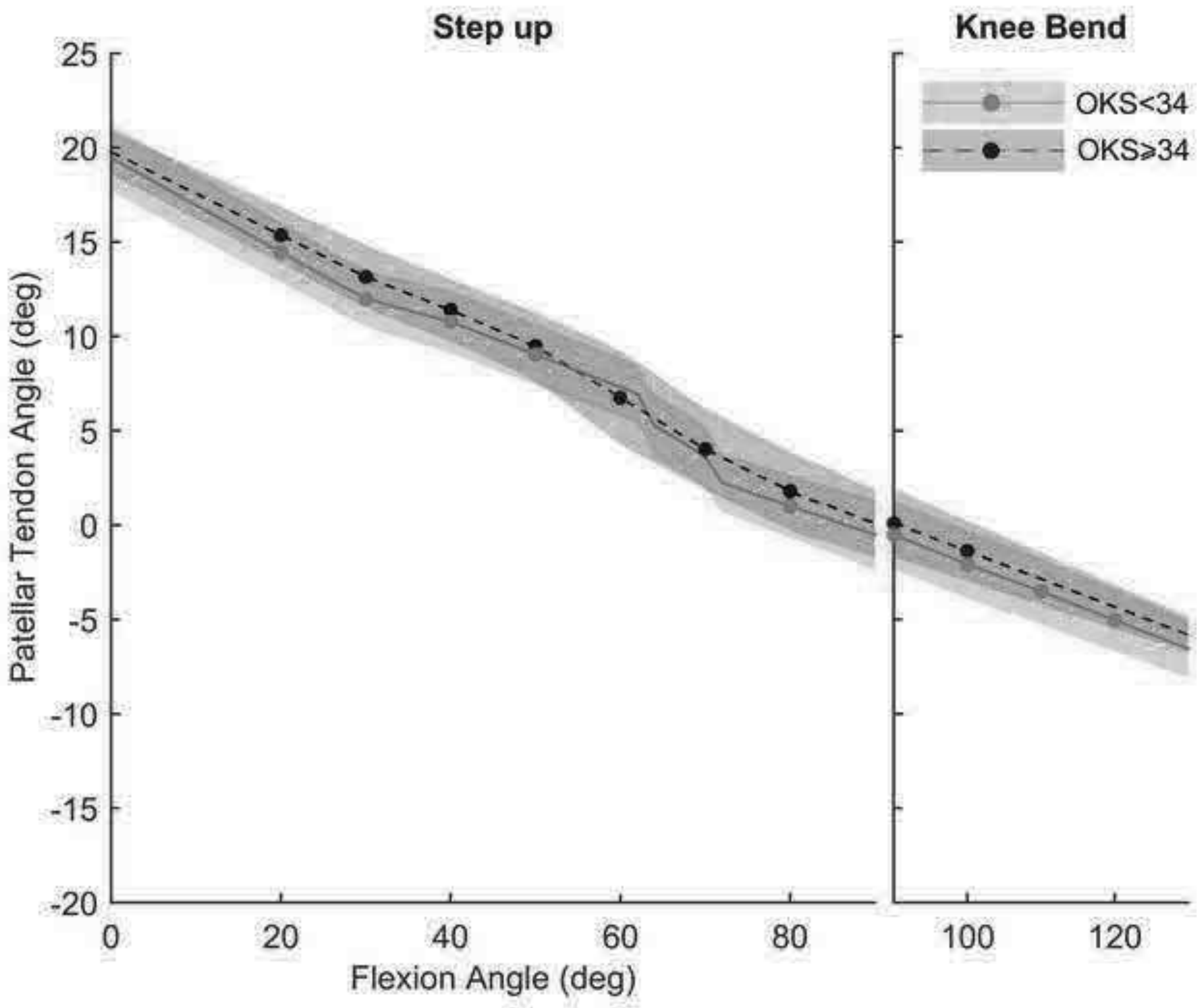

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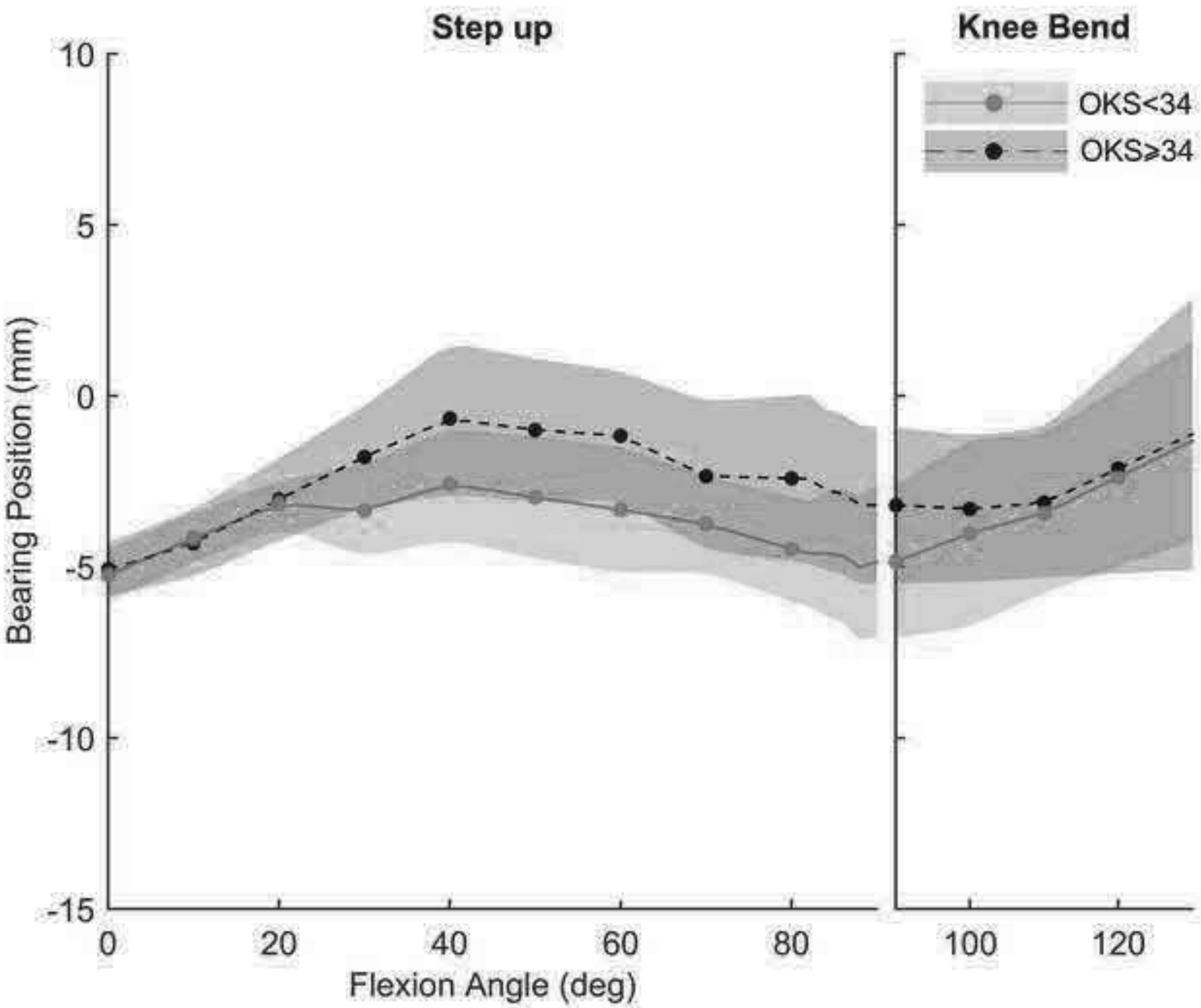

Figure Legend Page (if figures are used)

Fig-1. Definition of Patellar Tendon Angle (PTA) and Knee Flexion Angle (KFA). PTA is the angle between the long axis of patellar tendon and the long axis of tibia; the KFA is the angle between the long axis of femur and the long axis of tibia.

Fig 2. Illustration of how the Bearing Position (BP) was calculated relative to the midpoint of the keel. BP is the position of the centre of articular surface of the polyethylene mobile bearing relative to the midpoint of the tibial tray keel.

Fig 3. Relationship between Patellar Tendon Angle (PTA) and Knee Flexion Angles (KFA) for both the groups. Error bars represent 95% confidence intervals.

Fig 4. Relationship between Bearing Position and KFA for both the groups. The error bars represent 95% confidence intervals.

Table 1

Table 1 – Demographic and functional outcome data for the OKS<34 (n=15) and OKS≥34 (n=15) groups

	OKS<34 group [Mean (range)(SD)]	OKS≥34 group [Mean (range)(SD)]	Statistical difference [p value (significance) (test applied)]
Age (years)	60.7 (range: 57 – 65) (SD 3.4)	60.1 (range: 55 – 67) (SD: 2.8)	0.64 **(NS)** (unpaired t test)
Sex	Male = 4, Female = 11	Male = 4, Female = 11	1 **(NS)** (Fisher's test)
Pre-operative OKS	10.7 (range: 5 - 16) (SD 3)	9.1 (range: 5 - 13) (SD: 2.5)	0.12 **(NS)** (Unpaired t test)
Post-operative OKS	29.9 (range: 22 – 33) (SD 2.9)	41.0 (range: 36 – 45) (SD: 2.7)	**p < 0.0001** (Unpaired t test)
Posterior tibial slope (degrees)	6.3° (range 4-10) (SD 1.62).	6.5° (range 2-17) (SD: 3.94)	0.81**(NS)** (Unpaired t test)
Tibial Component coronal alignment	0.73° valgus (range 5° varus to 6° valgus, SD 2.79°)	0.93° varus (range 4° varus to 5° valgus, SD 2.49°)	0.095 **(NS)** (Unpaired t test)
Femoral Component Sagittal alignment	0.27° flexion (range 2° extension to 3° flexion, SD 1.22°)	0.73° flexion (range 2° extension to 2° flexion, SD 1.16°)	0.29 **(NS)** (Unpaired t test)
Femoral Component Coronal alignment	0.73° valgus (range 5° varus to 4° valgus, SD 3.24°)	0.8° valgus (range 6° varus to 5° valgus, SD 4.11°)	0.96 **(NS)** (Unpaired t test)
Time taken for the exercises (seconds)	12.7 (range: 9-19) (SD 2.7)	12.8 (SD: 2.2) (range: 10-18)	0.88 **(NS)** (Unpaired t test)
Follow up period (months)	17.8 (range: 12-24) (SD 4)	16.8 (range 12-24) (SD: 3.5)	0.47 **(NS)** (Unpaired t test)

Implant sizes	Median: extra small Range: extra small – medium	Median: small Range: extra small-large	0.43 **(NS)** (Mann Whitney U test)

NS = Non-Significant
SD = Standard Deviation