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## Posterior Bearing Overhang Following Medial and Lateral Mobile Bearing Unicompartmental Knee Replacements.

**KEYWORDS (5):** *Unicompartmental Knee Replacement Mobile Bearing.*

**RUNNING TITLE:** *Bearing Overhang in Oxford UKRs.*

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*All authors have made substantial contributions to either; research design, acquisition, analysis and interpretation of data; or drafting of the paper and revising it critically.*

*All authors have read and approved the final submitted manuscript.*

### Abstract

This study explores the extent of bearing overhang following mobile bearing Oxford unicompartmental knee replacement (OUKR) (Oxford Phase 3, Zimmer Biomet). The Oxford components are designed to be fully congruent, however knee movements involve femoral rollback, which may result in bearing overhang at the posterior margin of the tibial implant, with potential implications for; pain, wear, and dislocation.

Movement is known to be greater, and therefore posterior overhang more likely to occur, with; lateral compared to medial implants, anterior cruciate ligament deficiency, and at extremes of movement.

24 medial, and 20 domed lateral, OUKRs underwent sagittal plane knee fluoroscopy during step-up and forward lunge exercises. The bearing position was inferred from the relative position of the femoral and tibial components. Based on the individual component sizes and geometry the extent the posterior part of the bearing which overhung the posterior part of the tibial component was calculated.

There was no significant posterior overhang in knees with medial implants. Knees with lateral domed implants exhibited overhang at flexion angles beyond 60°, the magnitude of which increased with increasing flexion angle, reaching a maximum of 50% of the bearing length at 140° (range 0-140°). This demonstrates a clear difference between the kinematics, and prevalence and extent of posterior bearing overhang between medial and lateral OUKRs.

### Introduction

Medial and lateral Oxford unicompartmental knee replacements (OUKRs) incorporate fully congruent, mobile, ultra-high-molecular-weight polyethylene bearings. The preservation of the cruciate ligaments plus the ability of the bearing to follow the path of the femoral component whilst sliding relative to the tibial component means the kinematics of knees with OUKR more closely resemble normal (unimplanted knees) compared to knees with total knee replacement (TKR) <sup>1</sup>. In addition to improved function <sup>2-5</sup>, patients can expect faster recovery <sup>6;7</sup>, and lower morbidity and mortality <sup>8-10</sup> compared to TKR.

In both medial and lateral OUKR the upper surface of the bearing is congruent with the spherical femoral component and the centre of the concavity in the bearing moves with the femoral component during knee flexion. The antero-posterior (AP) location of the centre of the bearing relative to the tibial component, referred to previously and here as “the bearing movement”, indicates the extent of translation of the femur

relative to the tibia. Bearing movement was determined previously using fluoroscopy<sup>11-14</sup>.

Studies on patients with medial OUKR revealed that bearing movement could be as high as 13.5 mm or 15 mm<sup>11; 12</sup>. Despite variation between patients and type of exercise undertaken, there was a trend towards posterior bearing movement with increasing knee flexion, similar to the normal knee<sup>15-18</sup>. It was also found that patients with medial OUKR and anterior cruciate ligament (ACL) deficiency had great variability in bearing movement compared to patients with an intact ACL<sup>13</sup>.

In lateral OUKR the bottom surface of the bearing is concave and congruent with the upper surface of the tibial component which is domed. Previous work with cadavers have shown there is a significant risk of posterior overhang during knee flexion (Figure 1).

Posterior overhang with either medial or lateral OUKR occurs when the bottom surface of the bearing goes beyond the posterior margin of the tibial implant. The occurrence and magnitude of posterior bearing overhang is of interest as it may be a factor contributing to bearing wear, bearing dislocation or pain due to soft tissue irritation.

While, anterior, medial or lateral bearing overhang can be seen at operation or assessed on standard radiographs as it tends to occur near extension, posterior overhang cannot be seen at operation and, as it is likely to occur in flexion, cannot be assessed with standard radiographs. Marked overhang of the antero-medial corner of the old symmetric bearings was thought to be a possible cause of pain, so when the anatomic bearings were introduced this corner was rounded off. In a similar manner, posterior overhang could possibly cause pain but because it has not been previously quantified *in vivo*, negative consequences cannot be attributed to it.

Recently, a radiostereometric analysis of 79 patients with medial OUKR found that half had medial bearing overhang, and that bearing wear increased by 0.014 mm/year for each mm increment in medial overhang<sup>19</sup>. The effect of posterior overhang on wear has yet to be studied.

The aim of the study was to use previously collected fluoroscopic data on patients with medial and lateral OUKR carrying out a step-up and a lunge to determine if posterior bearing overhang occurred during knee flexion. Our null hypothesis was that bearing overhang does not occur in either compartment at any angle of knee flexion/extension.

## Methods

### Level of Evidence II

#### Patients

We obtained data, for this prospective cohort study, from two fluoroscopic studies which both assessed sagittal plane kinematics during step-up and forward lunge exercises for medial<sup>13</sup> (n=32) and lateral<sup>20</sup> (n=20) OUKR. The original cohort of medial implants consisted of 26 patients, with 32 implants, from operations performed

between January 2000 and June 2011. These patients were originally matched cohorts for ACL deficient (n=16) and ACL intact (n=16) knees<sup>13</sup>. The cohort of lateral implants consisted of 18 adult patients, each with a lateral domed implant, from operations performed between January 2003 and August 2005.

The medial and lateral cohorts had mean ages and range of 67.4 (49-87) and 63.4 (46-78) years respectively (p=0.94).

All implants were conducted at Oxford Hospitals by experienced surgeons. They were performed for a pre-operative diagnosis of isolated compartmental osteoarthritis (OA). All patients received Oxford Phase 3 components, and a standard post-operative rehabilitation. The study protocols were approved by the relevant local ethics committees.

At the time of operation; 3 medial patients had bilateral implants, no lateral patients had bilateral implants, and neither medial nor lateral patients had bicompartamental implants.

The medial cohort contained some implants for which the component sizes could not be determined. Calculations of overhang are dependent on component size, and therefore we had to exclude these patients from the current study. This reduced the medial cohort to 21 patients in total (24 implants); 14 patients with ACL deficient knees (16 implants), and 7 patients with their ACL intact (8 implants). We note that the remaining ACLD/ACLI groups remained similarly balanced for; age, follow-up and gender, however they are reduced in size and have a higher than population male to female ratio. The mean age and range of the ACLD patients changed from 67.0 (50–87) to 67.3 (50–87), while the mean age and range for ACLI patients changed from 68.3 (49–86) to 67.4 (49–86). The mean time to follow-up for ACLD from 6.3 (1.3–12.8) to 5.8 (1.3–12.8) and for ACLI changed from 6.0 (2.6–11.0) to 4.7 (2.6–11.0). Student t-tests for the ages and follow-up comparing the new ACLD/ACLI cohorts were p=0.94 and p=0.39 respectively. Gender comprised of; 13 male, 1 female within ALCD and; 7 male, 0 female with ACLI, chi-square comparison gives p=0.46. There was no missing component size data in the lateral cohort.

#### Data Acquisition

All knees were imaged through their full range of active motion, by performing step-up and lunge exercises on a platform, (Figure 2), under continuous fluoroscopic imaging from a fixed position from the side of the knee. Step-up and lunge activities were chosen because they respectively maximised and minimised strain on the ACL, whilst allowing for a large range of flexion to be performed under load<sup>21</sup>.

Fluoroscopy allows calculation of location of the midpoint of the bearing along the AP axis of the tibial component, and the flexion angle of the knee, the methods for which are previously published<sup>1; 13; 20</sup>, and are also described below.

The sizes for components used for individual patients were obtained from the original records. Bearing and tibial component dimensions were obtained directly from the manufacturer (Zimmer Biomet, Swindon, UK).

## Determination of Knee Flexion Angle (KFA) and Bearing Position (BP)

Briefly, the individual fluoroscopy frames were corrected for distortion for each patient individually using a global correction method, which corrects for the effects of distance from the fluoroscopic source<sup>20</sup>. Points on the images are manually identified using a custom routine in Matlab (Mathworks, USA), which locates the centres of the femoral and tibial components along the anterior posterior axis of the implant, and calculates the Knee Flexion Angle (KFA), and Bearing Position (BP)<sup>1;13</sup>.

The centre of the tibial plates are determined from locating the central keel point. This point is invariant under rotation of the implant relative to the observer, and lies directly underneath the midpoint of the tibial implant surface. The centre of the femoral component is located by fitting a circle to the silhouette and calculating the central point of this circle. The perpendicular line is calculated by taking a normal to points plotted along the keel slot, which is parallel to the tibial implant surface.

BP is determined, despite the bearing not being visible on the fluoroscopic images, because the thinnest part of the bearing, the minimum joint space width (mJSW), will always lie under the centre of curvature of the femoral component when under load. The mJSW is located at the geometric centre of the lateral bearings, but shifted towards the posterior edge in medial bearings. The centre of the femoral component is located by fitting a circle to the silhouette and calculating the central point of this circle. The perpendicular line is calculated by taking a normal to points plotted along the keel slot, which is parallel to the tibial implant surface.

The method thus far in calculating BP is the same for both medial and lateral components, and at this stage represents the AP displacement of the centre of the femoral component. Calculation of Overhang from this BP is different for medial and lateral implants as follows.

### Medial OUKR

Bearing overhang is given by a simple subtraction of lengths, (Figure 3): Figure 3:

$$\text{Overhang} = \text{Tibial Plate} - \text{Bearing} - \text{Bearing Position (BP)} \quad (1)$$

Positive values for overhang represent full contact with the tibial plate, a zero value indicates the most posterior part of the bearing is at the most posterior part of the tibial sliding surface, and negative values represent posterior overhang of the bearing beyond the posterior margin.

### Lateral OUKR

While the tibial component for medial OUKR has a flat surface, the domed surface of the lateral tibial component necessitated an alternative calculation for bearing overhang, based on arc lengths, as opposed to straight lines.

The angle, Alpha, is the angle subtended by a normal from the centre of curvature of the tibial component through its own midpoint, and a line linking the centre of curvature of the tibial and femoral components. Alpha is given by

$$\text{Alpha} = \sin^{-1}\left(\frac{BP}{(R1+R2+D)}\right) \quad \text{Alpha's units are Radians} \quad (2)$$

*From fluoroscopy:*

*BP = perpendicular distance between the centre of the femoral implant from the vertical.*

*From Component Dimensions:*

*D = mJSW (Which occurs at the midpoint for both length and width in lateral bearings),*

*R1 = the radius of the tibial implant domed surface,*

*R2 = the radius of the femoral component,*

*X = straight line distance from midline to posterior edge of tibial component sliding surface.*

The lateral domed bearing is symmetrical, with length W, and lower surface radius matching exactly the dome of the tibial component, R1. Therefore the surface arc from bearing midline to posterior margin, (Figure 4), L1, the longer blue section, can be calculated as;

$$L1 = R1 \sin^{-1}\left(\frac{W/2}{R1}\right) \quad (3)$$

The arc of displacement of the bearing's mid-point (mJSW) from the midline, (Figure 4) L2, the shorter blue section, runs along the surface of the tibial component. L2 is given by;

$$L2 = R * \text{Alpha} \quad (4)$$

The length of sliding surface available from midpoint to posterior edge of the Tibial Implant, shown in (Figure 4) as the green line, and annotated L3 is given by;

$$L3 = R1 \sin^{-1}\left(\frac{x}{R1}\right) \quad (5)$$

The overhang arc length was then calculated by subtraction of these arc lengths;

$$\text{Overhang} = L3 - (L1 + L2) \quad (6)$$

### Data Analysis

The tibial component length is taken as the maximum length of the implant, which occurs adjacent to the lateral retaining wall. The posterior margin of the implants then curve to match the natural shape of the tibia, which is not accounted for in this paper. An assumption is made that the bearing is travelling whilst fully conforming with the tibial implant surface, parallel to the retaining wall, without rotation.

The KFA data was grouped into 10° intervals for analysis, i.e. all values for KFA between 5.0° and 14.9° were assigned to the set covering the 10 degree interval. The

mean was calculated using a smoothing function, using weighted datapoints adjacent to the 10° interval, to reflect the fact that physical reality requires a continuous movement of the bearing in space. 95% confidence intervals for the mean were calculated assuming that readings were normally distributed using standard deviation.

Finally the resulting measurement of overhang in millimetres can be normalised for each implant individually, as shown in Figure 5.

Normalised Overhang is given by;

$$\text{Normalised Overhang (Percentage)} = \frac{X}{Y} * 100$$

Where, X= Overhang, and Y = total length of sliding surface of the bearing.

### Accuracy

The accuracy of our system was assessed by moving components known distances under fluoroscopy within the sagittal plane. Three frames were taken at 10 different positions, giving a total of 30 images. Accuracy was then calculated by comparison of the relative movements of the tibial and femoral components, to the known shift in their relative positions.

### Results

#### Medial Cohort

Overhang is found (Figure 6) in a medial implant in an ACLD deficient knee (representing a single implant, with a large size bearing and size E tibia) at 0° of extension, this datapoint is outside the 95% confidence interval for the cohort as a whole at 0°. None of the remaining fluoroscopic images showed overhang, from any of the 21 patients (24 implants). In addition, 95% confidence intervals show that overhang would be most likely at the extremes of extension, beyond 120°, where confidence intervals widen due to the relatively lower number of datapoints, and their averages move posteriorly. Only two knees reach 130°. By taking a smoothed average or fitting a polynomial, as shown by the red dashed line, the pattern of most likely movement is determined. Overhang is therefore effectively excluded, to at least 95% confidence, at ranges between 5° and 120° in medial OUKRs, and furthermore if it were to occur would be most likely at either full extension or flexion beyond 120°.

#### Lateral Cohort

Patients with Lateral OUKR, showed significant overhang (Figure 7). Beyond 60° flexion over half of participants showed bearing overhang. At 130° all lateral implants were overhanging. The largest overhang being 16 mm of bearing surface in a patient with medium sized components. When converted to show overhang length as a percentage of total bearing length, 16 mm represents 51% of this 28 mm long bearing.

Analysis of ACL deficient (Figure 8) vs. ACL intact (Figure 9) within the medial cohort showed little difference between the two in terms of average movement profile of the two groups at flexion angles up to 100°, at which point the ACL deficient group

bearing average position moves posteriorly. The outlying point at 0 degrees in the ACL deficient group is overhanging, but is beyond the 95% confidence interval for the mean of all knees at 0 degrees. This point represents therefore an outlier, but is significant in demonstrating that some individuals will be capable of posterior overhang at full extension. The comparison between groups shows that the likelihood of an individual knee exhibiting overhang is increased if ACL deficient, and at either full extension or high flexion.

### Accuracy

Measurements of component position when the components were moved known distances parallel with the sagittal plane had a mean error of 0.006 mm (SD 0.34 mm), with root mean square error (RMSE) of 0.23mm. Therefore we consider our system to be accurately determining AP bearing position to within +/-1mm with the assumption that the bearing remains parallel with the wall of the tibial component.

### Discussion

The results of this study suggest that all patients that receive a domed lateral OUKR are likely to have posterior bearing overhang at flexion angles above 130° and that half of patients will exhibit bearing overhang at angles of 60° and above. In contrast, patients that receive medial OUKR do not exhibit bearing overhang between extension and 120° flexion. The only exception is that following medial OUKR with a deficient ACL there appears to be a small risk of slight posterior overhang in full extension.

The extent of the posterior overhang of the lateral bearing in high flexion is marked, being on average 40% of the bearing length in 140 degrees flexion. The extent of the overhang can clearly be seen in cadavers with the domed lateral OUKR implanted (Figure 1), but has not been assessed *in vivo* before. This extensive posterior movement and overhang is what would be expected considering that, the domed lateral OUKR restores normal knee kinematics and that in the normal knee there is marked lateral roll back in high flexion<sup>16; 17</sup>. Indeed, in high flexion in the normal knee, the lateral femoral condyle articulates with the convex surface of the back of the lateral tibial plateau and the posterior horn of the lateral meniscus subluxes off the lateral tibial plateau<sup>15; 16; 22</sup>, in a similar manner to that seen with the lateral OUKRs. In a comparative study we found that following lateral UKR, knees with a convex domed tibia flexed more than with a flat tibia and had both greater and more normal posterior movement of the femoral condyle, presumably because the tightening of the soft tissues laterally with the flat component prevents the normal roll back in high flexion<sup>23</sup>. Therefore the marked posterior overhang in high flexion with the domed lateral OUKR is advantageous as, unlike other designs of knee replacement, it allows normal kinematics in high flexion.

The marked posterior overhang of the domed lateral bearing in high flexion may, potentially, cause problems. If the overhang is greater than 50% there may be edge-loading on the back of the tibial component. The risks of this should be minimised by the surgeon ensuring that the tibial component reaches, or slightly overhangs, the posterior tibial cortex, and that there is no retained posterior cement. There is a potential concern that if the bearing overhangs extensively in high flexion, it might jam and not return to its normal position as the knee extends. This might cause

posterior pain or locking, but we are not aware of this ever happening. The extensive overhang may be a risk factor for dislocation. However, if the overhang was to cause a dislocation it would probably be a posterior dislocation, which is very rare<sup>24;25</sup>. The common mode of dislocation occurs when the bearing subluxes medial and superiorly over the tibial vertical wall and ends jammed on top of the wall<sup>25</sup>. It is not clear if posterior overhang would contribute to this mode of dislocation.

With extensive overhang the contact area between the metal and polyethylene would decrease with an associated increase in contact stress and thus potentially more wear. We also know that in high flexion force transmitted across the knee can increase, up to 2.5 times body weight in a squat, however that this load also redistributes with the medial compartment taking a greater share of the load as flexion angle increases<sup>26</sup>. This mixed picture makes it hard to predict the potential stress multiplier caused by overhang in the lateral compartment, and even if this were to be done via computational modelling, or an instrumented prosthesis, we would not know how this would affect wear rates in-vivo. We are not aware of any in vivo wear studies of the domed lateral OUKR, so we cannot be certain that overhang will not cause wear problems. An RSA wear study is needed to investigate this.

With medial OUKR we did not find significant bearing overhang. The main reason for this is that there is much less movement in the medial than the lateral compartment. Although bearing movement was seen in all patients and varied considerably between patients, the movement was limited and posterior overhang did not occur with flexion. Another factor that would decrease overhang is that the medial tibial plateau is longer than the lateral and the medial bearing is shorter. As a result, the proportion of the tibial plateau covered by the bearing is on average 61% for medial components and 71% for lateral components. This means that more movement is required medially to cause overhang. The mobile bearing therefore seems to be ideal for the medial compartment with the large areas of contact minimising wear, the freely moving bearing minimising sheer stress at the bone-implant interfaces and therefore minimising the risk of loosening, and the absence of overhang, which could potentially cause problems.

The ACL tends to hold the femur forward relative to the tibia, and therefore should limit posterior overhang. Occasionally, for example to minimise the risk of medical complications in elderly patients, we would implant OUKR in knees that were ACL deficient but were otherwise appropriate. In our previous study of bearing movement we found that ACL deficient OUKRs had greater variability in kinematics than those with the ACL intact, and we therefore suspected that they might have posterior overhang<sup>13</sup>. We did find in one patient there was slight overhang in full extension, suggesting that even with ACL deficiency overhang is very unlikely.

For this study, patients did two exercises: a step up and a forward lunge. The lunge achieved the greatest flexion with the foot being on a step and the patient pushing forward and flexing the knee under load. In this study, following medial OUKR, all patients achieved at least 120° of knee flexion. Up to 120° there was no overhang but the trend was towards increasing posterior bearing movement with increasing flexion. Therefore in higher degrees of flexion some posterior overhang may occur. However, repetitive functional activities tend not be done at these high flexion angles, so this overhang probably would not be associated with increased wear. The situation may be different in countries where high knee flexion is required for cultural and social

reasons. It would therefore be important to repeat the study in patients from these countries.

The main limitation of the study is that all the assessments were done in two dimensions focusing on antero-posterior (AP) movement, but not medio-lateral (ML). This means that neither bearing rotation, nor medio-lateral position are known or accounted for. Determining position would require bi-plane fluoroscopy or RSA. Determining rotation in addition would require either specially marked bearings, or cross-sectional imaging, possibly a CT scan. However cross-sectional imaging would be difficult during functional activities.

It was assumed that if the back of the bearing did not extend further back than the back of the tibia there would be no overhang. However, if, with increasing flexion, the bearing tracked postero-medially or externally rotated the bearing might overhang postero-medially even though it was not overhanging posteriorly.

Another limitation is that all the patients assessed had a good clinical outcome and a high level of function. If overhang was occurring and causing problems such as pain, dislocation or wear we would not have identified this as we did not study these type of patients. Further study is needed now we have established the overhang does not occur medially under normal circumstances.

[Further study into posterior bearing overhang, and it's potential relationship to wear rates, in light of the recent study relating medial bearing overhang to wear<sup>19</sup>, could be considered. Additional research opportunities also exist into the existence of medial implant posterior overhang in diverse populations and at high flexion angles, as does the use of 3D imaging to better understand the prevalence of medio-lateral movement and rotations.

## Conclusion

Little is known about posterior overhang of mobile bearings in knee replacement. In particular there is little information about whether it occurs and its consequence, although theoretically it may contribute to dislocation, wear or adverse symptoms. This is the first study of posterior bearing overhang following mobile bearing OUKR. Domed lateral OUKRs exhibit substantial posterior overhang in high flexion in all cases. This occurs because, unlike other types of knee replacement, the domed lateral UKR restores normal lateral roll back in high flexion<sup>20</sup>. In contrast we found that posterior bearing overhang did not occur following medial OUKR in the functional flexion range. The only exception is that with a deficient ACL there appears to be a small risk of slight posterior overhang in full extension.

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FIGURES

Figure 1: Cadaveric model of a Lateral domed OUKR showing posterior overhang at high flexion angles.

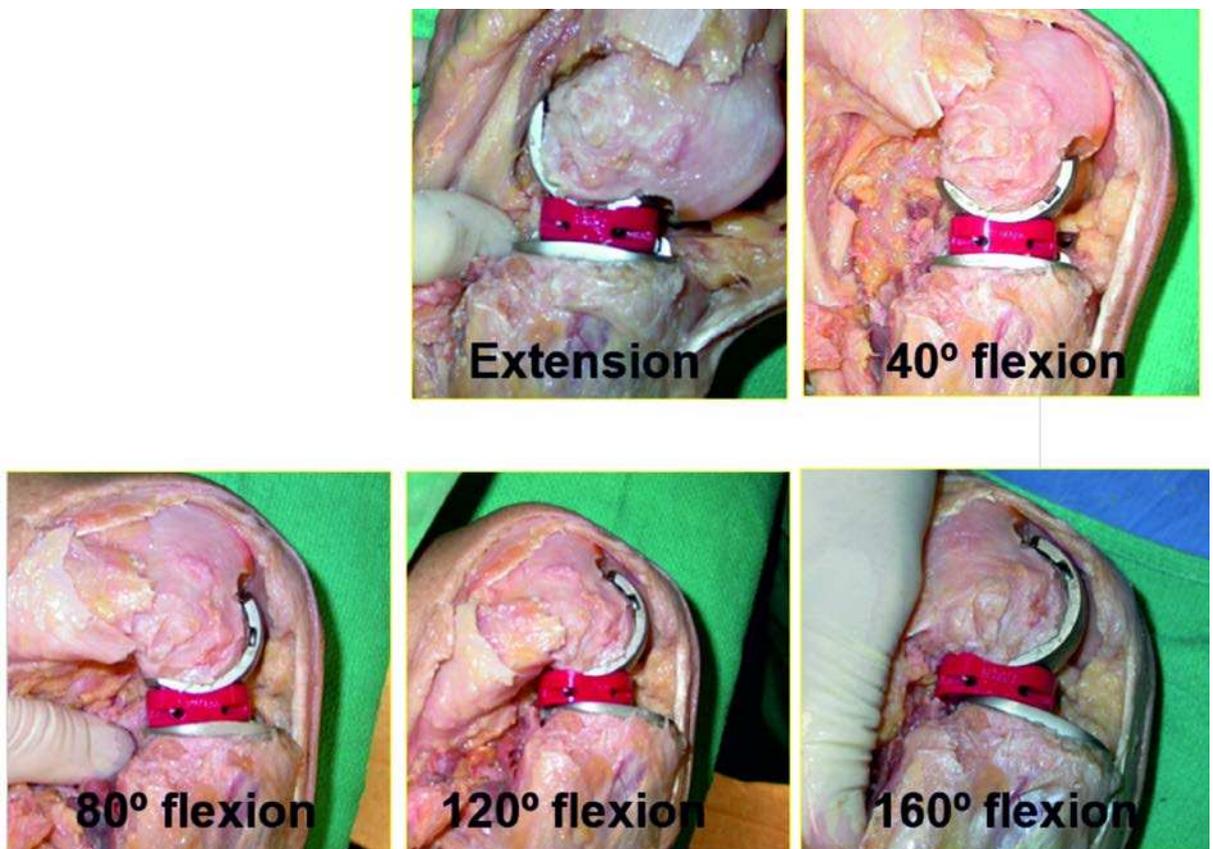


Figure 2: Patient Movements; A) Step and B) Lunge.

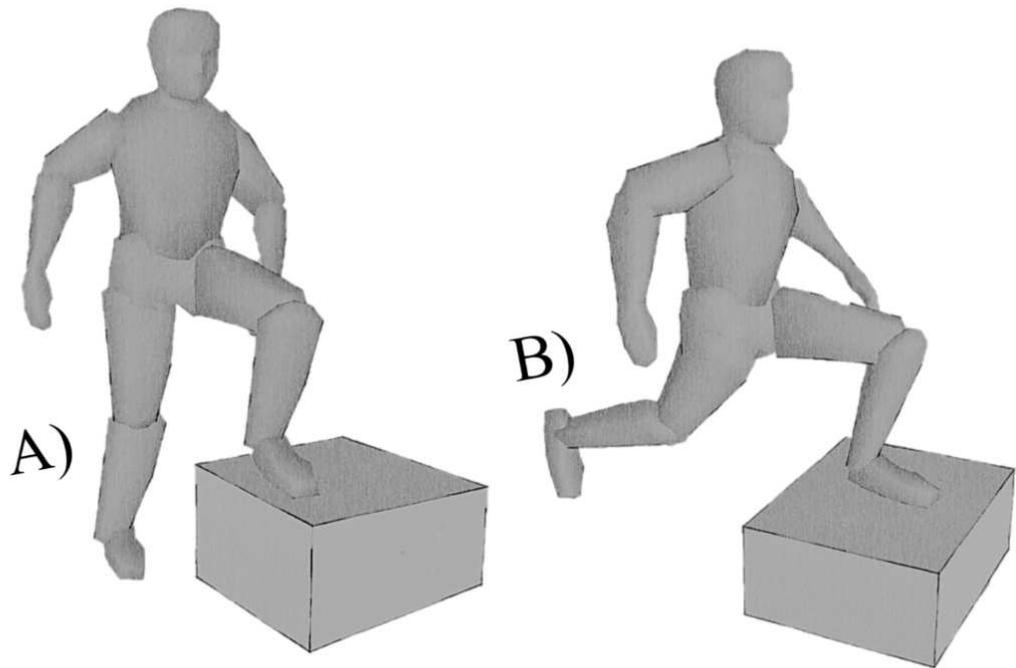


Figure 3: Diagrammatic representation of the geometry of the medial OUKR, with dimensions and orientations required for calculation of bearing overhang. “Tibial Plate” = the length of sliding surface available from the centre of the keel slot to the posterior edge of the tibial implant. “Bearing” = the length of sliding surface available from midpoint of the bearing (mJSW) to the posterior edge of the bearing.

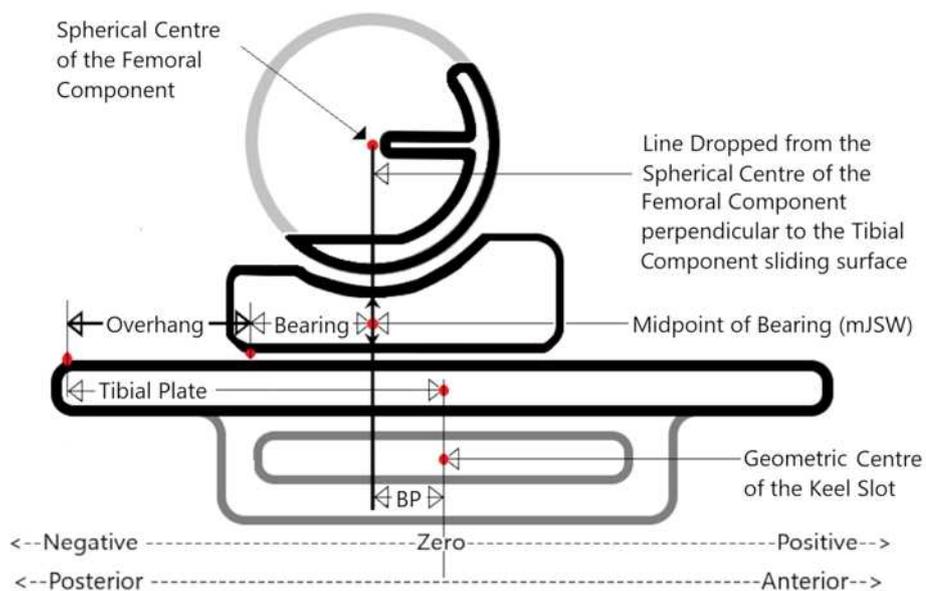


Figure 4: Diagrammatic representation of the geometry of the lateral domed OUKR, with dimensions and orientations required for calculation of bearing overhang.

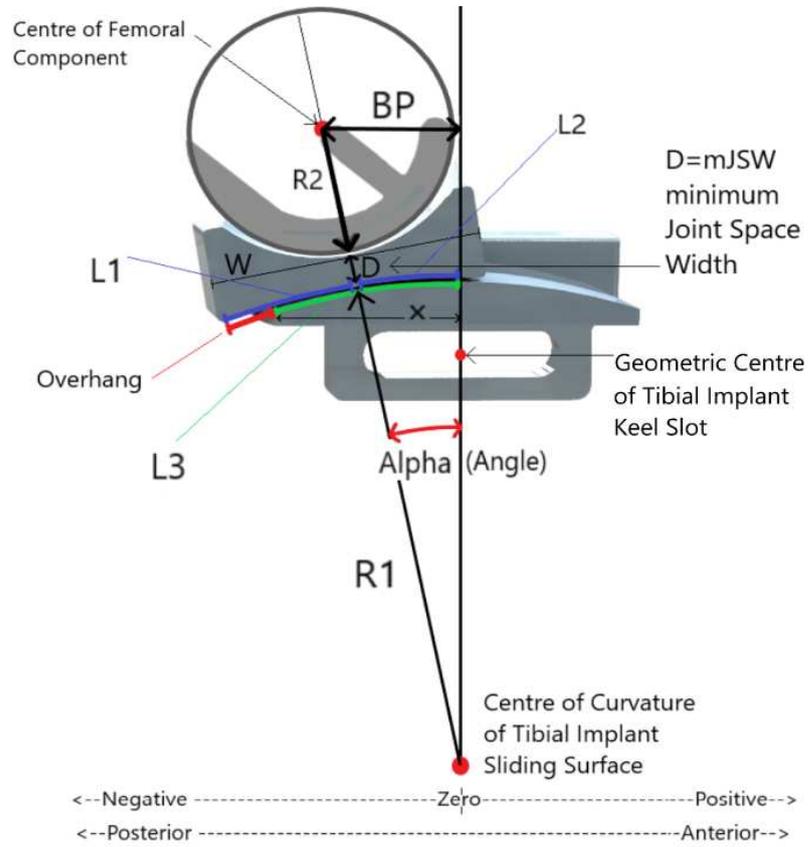


Figure 5: Dimensions required for calculations of normalised overhang

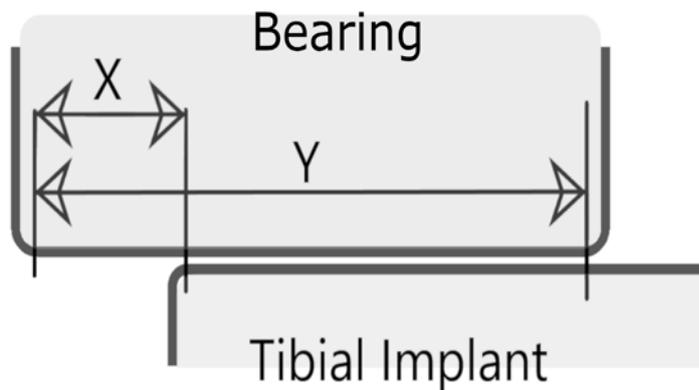


Figure 6: Overhang vs. flexion for medial OUKR, normalised as a percentage of bearing total length.

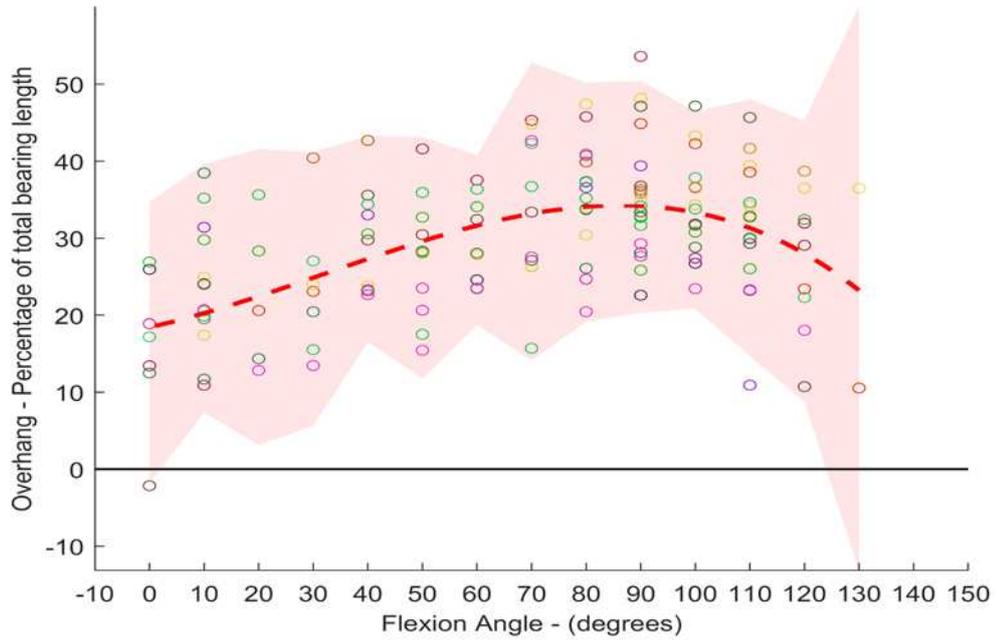


Figure 7: Overhang vs. flexion for lateral domed OUKR, normalised as a percentage of bearing total length.

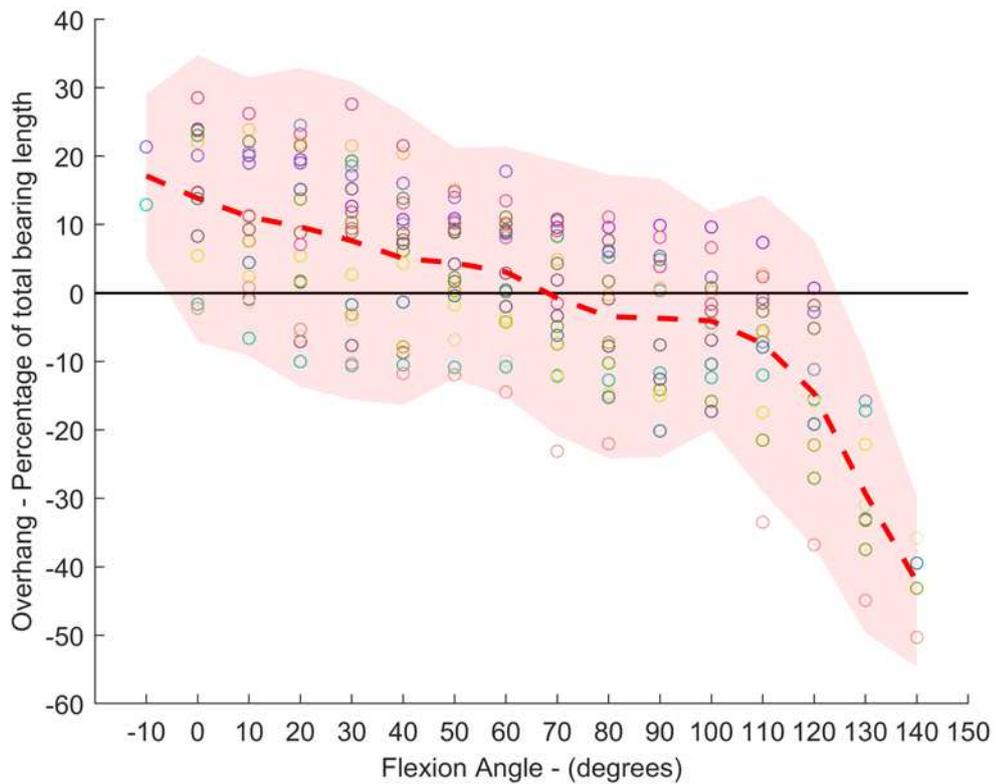


Figure 8: Overhang vs. flexion for ACLD medial OUKR, normalised as a percentage of bearing total length.

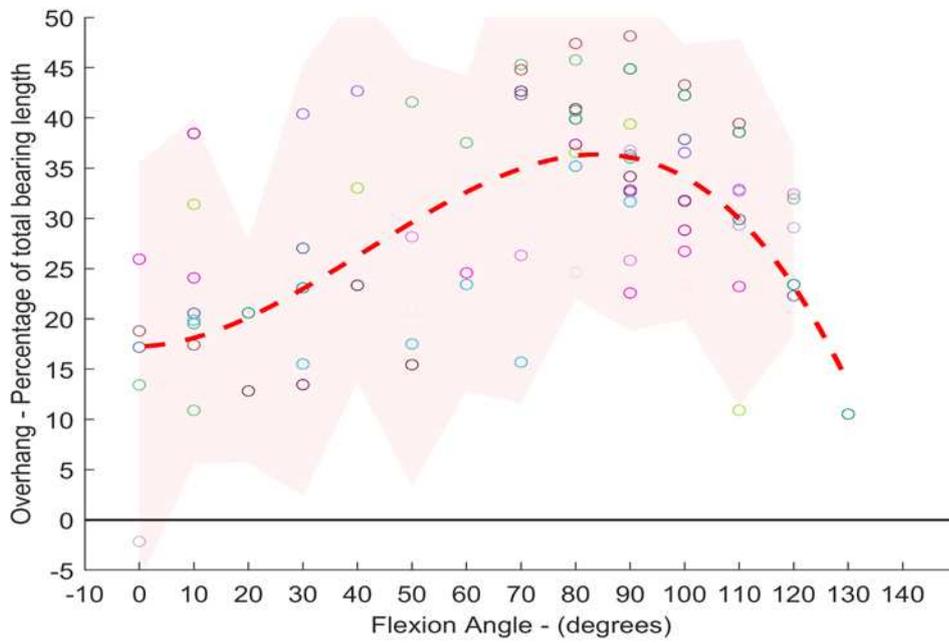


Figure 9: Overhang vs. flexion for ACLI medial OUKRs, normalised as a percentage of bearing total length.

