

- 1 **Functional outcome and revision rate are independent of leg alignment following**
- 2 **medial Oxford UKR**

Abstract

Background: There is controversy about optimal alignment following knee replacement. An aim of the use of medial Oxford unicompartmental knee replacement (UKR) is to accurately restore normal ligament tension in the knee, thereby restoring normal kinematics. This typically results in a return to pre-arthritic alignment, which is frequently varus. The aim of this study was to investigate the relationship between post-operative leg alignment and post-operative patient-reported outcome and implant revision.

Methods: We used a consecutive cohort of 891 cemented Oxford medial UKR with mean ten year follow-up and recorded alignment. We grouped knees according to post-operative mechanical alignment as marked varus (about 10°), mild varus (about 5°), neutral and valgus. The mean Oxford Knee Score (OKS) was calculated at five and ten years. Revision risk was assessed by survival analysis and component-time incidence rates.

Results: Sixty-seven knees (8%) were in marked varus, 308 (35%) in mild varus, 508 (57%) in neutral, and 8 (1%) in valgus. **The valgus group were too small for further analysis.** Mean OKS at ten years was 42 (SD 7) for marked varus, 41 (SD 8) for mild varus, and 39 (9; $p=0.28$) for neutral. At ten years 92%, 85% and 76% achieved good or excellent OKS outcome respectively ($p=0.02$). Twelve-year survival rates were respectively 93.3%, 93.2%, and 93.6% ($p=0.53$). Revision incidence rates per 100 component years were respectively 0.49 (95% CI 0.2 to 1.5), 0.36 (CI 0.2 to 0.7), and 0.54 (CI 0.4 to 0.8) and were not significantly different ($p=0.53$).

Conclusions: Marked postoperative varus mechanical alignment of about 10° was present in 8%, and mild varus of about 5° in 35%. **Increasing varus alignment was associated with an increasing** percentage of good or excellent OKS outcomes, but otherwise there were no significant differences between alignment groups in patient-reported outcome or revision rate.

- 27 This data supports the surgical technique for the Oxford UKR, which aims to restore ligament
28 tension and therefore pre-arthritic alignment rather than neutral mechanical alignment.
- 29 **Level of Evidence: III**

Introduction

Optimal leg and knee alignment in total knee replacement (TKR) continues to be a subject of controversy¹, with hopes that a targetable and reproducible alignment will lead to better patient function, increased satisfaction, and better implant survival. Traditional approaches attempted to evenly load force across components by creating a neutrally aligned knee in a neutrally aligned leg, where the straight mechanical axis passes through the femoral head center, through the knee center, to the ankle center, and the components are perpendicular to the mechanical axis. This is often different to a patient's pre-arthritis anatomy and alignment, which is frequently varus². More recent approaches have aimed to more closely restore knee anatomy but there is concern that if the leg is in excess varus the eccentric loading on components will result in loosening. It is not known how much varus is acceptable.

In contrast to TKR, in unicompartmental knee replacement (UKR) leg alignment is determined primarily by the thickness of the implant rather than component alignment³. Furthermore, with a spherical femoral component and mobile bearing the center of the Oxford UKR is independent of implant alignment unless there is gross malalignment. The indications and surgical technique for the medial mobile-bearing Oxford UKR have been developed over the last 40 years and are now well defined and evidence based⁴. To satisfy the indications all ligaments should be functionally normal. During the operation ligaments are never released; restoration of ligament balance and normal tension is achieved by incrementally removing bone from the distal femur and inserting a bearing of appropriate thickness. As a result normal knee kinematics and pre-arthritis alignment are restored^{5, 6}. As the bearings are in thickness increments of 1mm the pre-arthritis alignment is restored to within approximately 1°. Gulati et al. in 2009, found no relationship between post-operative leg alignment and functional outcome, however, the numbers and length of follow up in the study were too small to investigate implant survival⁷. There therefore remains concern that this surgical approach,

which often results in varus leg alignment may be associated with an increased failure rate. Due to this concern proponents of fixed-bearing UKR have different surgical techniques and aim for different post-operative alignments compared to mobile-bearing UKR^{8,9}. The purpose of this study was to investigate the effect of postoperative coronal leg alignment on long term patient-reported outcomes and implant survival in a large sample of knees that had undergone medial Oxford UKR.

Materials and Methods

Observational data from a designer cohort of cemented medial Oxford UKR was used to assess the influence of coronal alignment on patient-reported outcomes and implant survival. One-thousand cemented medial Oxford mobile-bearing Phase 3 UKR (Zimmer-Biomet, Bridgend, United Kingdom) were performed using a minimally invasive approach by two designer surgeons (CAFD, DWM) from June 1998 to March 2009 (818 patients) for the recommended indications as described by Goodfellow et al¹⁰. The majority (977 knees) had anteromedial osteoarthritis, and 23 had spontaneous osteonecrosis of the knee. This cohort had mean 10 year follow up (range, 5 to 17), and has previously been reported^{11, 12}; the present study was designed to specifically explore the effect of coronal alignment on outcomes. Follow up was by research physiotherapists independent of clinical teams involved in patient care. Function was assessed by patient-reported outcome measures (PROMs), the Oxford Knee Score (OKS; 0 to 48 with 48 the best outcome)¹³, and Tegner Activity Score (TAS; 0 to 10 with 10 being participation as an elite athlete)¹⁴, and the clinician assessed American Knee Society Score Objective (recorded without deduction for coronal alignment) and Functional components (AKSS-O and AKSS-F; 0 to 100 with 100 being best)¹⁵. Reviews were scheduled at one, five and ten years post-operatively. Data were extracted from our prospectively maintained database on September 1, 2014. All patients were contacted in the preceding 18

months to record the current functional status of their knee and to identify any re-operations/revisions. If a patient had died, information about their knee and any further operation was obtained from primary and secondary care records and from the patient's relatives where appropriate. Ethical approval was sought from our local research ethics council (**Oxfordshire REC**), with formal approval deemed **unnecessary under National Health Service research governance arrangements**.

Coronal alignment was measured routinely at post-operative clinic appointments by trained physiotherapists. Our method of measurement has previously been described⁷. Measurements are made with the patient standing, and the center of the ankle, the knee and the anterior superior iliac spine (ASIS) are palpated and the leg alignment measured with a long arm goniometer aligned to the bony landmarks. The mean difference between the physiotherapists has been quantified at 0.7° (SD 2.5), and validation against long-leg radiographs demonstrated the mean angle between the femoral anatomical axis and the line from the center of the knee to the ASIS was 0.8° of valgus (SD 0.5, range 0.1° to 1.4°)⁷. The long arm goniometer measurements were therefore considered an accurate measurement within one degree of coronal anatomical leg alignment.

Coronal anatomical alignment measurements were categorized according to the AKSS into four anatomical alignment groups with their associated mechanical alignments¹⁵: >10° anatomical valgus (considered mechanical valgus), 5° to 10° anatomical valgus (mechanically neutral), 0° to 4° anatomical valgus (mechanically mild varus, about 5°) and <0° anatomical valgus (mechanically marked varus, about 10°). We used the latest post-operative recorded alignment. The bearing wear of the Oxford UKR has an average linear penetration rate of 0.02 mm/year¹⁶, and thus we assumed that alterations in alignment due to wear over ten years would be substantially less than one degree.

Age and weight at surgery were normally distributed. Pre-operative OKS was normally distributed, whilst post-operative scores were left skewed. Tegner activity score was normally distributed pre- and post-operatively.

PROMs and AKSS are presented as mean (standard deviation) scores. Differences between groups were tested with Analysis of Variance (ANOVA) with Bonferroni correction, whilst differences over time within a group were assessed with paired t-tests. The percentage of knees at each time point achieving an OKS of 34 or greater (considered a good or excellent outcome) was calculated. We performed a Chi square test for a trend to test significance.

Revision was defined, as per the National Joint Registry of England, Wales, Northern Ireland and the Isle of Man (NJR)¹⁷ as component removal, exchange or addition. It therefore included insertion of a new bearing (for example, following dislocation or after a washout), addition of a lateral UKR or conversion to a TKR. Component-time incidence rates for overall and individual failure modes were calculated, and significance was tested with a log-rank test for a trend. Kaplan-Meier survival estimates were determined for each alignment category. Four knees (three patients) were lost to follow up prior to one-year so their final revision status remains unknown. Coronal alignment was missing in 109 knees (11%), including 11 revisions (21% of revisions), and these were excluded for the analysis (case-wise deletion). Patient records were checked, and these knees had either undergone early censorship (revision [n=5] or death [n=8]), were lost to follow up (n=4) or had entirely remote follow up (postal and phone questionnaires [n=92]).

Source of funding:

The author or one or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article. The funding source played no role in the design, conduct or interpretation of this study.

Results

Post-operative limb alignment was available for 891 knees (89%). Of these, 67 were in marked varus (8%), 308 in mild varus (35%), 508 in neutral (57%), and 8 in valgus (1%). There were considered to be too few in valgus for meaningful interpretation, and these were excluded for further analysis. The groups were well matched in age, weight, preoperative OKS and preoperative TAS (Table 1). Increasing varus categorisation was associated with male sex ($p<0.001$).

There was significant improvement in all patient-reported outcome scores with UKR for all alignment categories ($p<0.001$). The mean preoperative OKS in marked varus, mild varus and neutral groups were 26.4 (SD 11), 25.0 (SD 9), and 24.5 (SD 9; $p=0.30$); at five years OKS were 42.0 (SD 7), 41.1 (SD 8) and 41.3 (SD 8, $p=0.74$); and at ten years the OKS were 41.7 (SD 7), 40.5 (SD 8), and 39.4 (SD 9; $p=0.28$); respectively. At five and ten years, most patients achieved a good or excellent OKS (figure 1). At five years 86% achieved a good or excellent OKS and there was no association with alignment category ($p=0.64$). However, at ten years, in the marked varus, mild varus and neutral groups 92%, 85% and 76% respectively achieved a good or excellent result and the association was significant ($p=0.02$). There were no differences in AKSS-O, AKSS-F or TAS (Table 2).

Kaplan-Meier survival estimates with revision as the endpoint at 12 years were 93.3% (at risk=13, CI 80-98), 93.2% (at risk=58, CI 86-97) and 93.6% (at risk=113, CI 91-96) and were not significantly different (Figure 2). Component time incidence rates per 100 component years were not significantly different between alignment categories ($p=0.53$), and were 0.49 (95% CI 0.2-1.5) for marked varus alignment, 0.36 (CI 0.2-0.7) for varus alignment, and 0.54 (CI 0.4-0.8) for neutral alignment. There were no significant trends in the modes of failure (Table 3).

Discussion

Our results demonstrate that 8% of knees treated with Oxford UKR in this study had marked **post-operative** varus leg alignment of about 10° and 35% had mild varus alignment of about 5°. They also show that there were no significant differences in functional outcomes or survival rates between those in marked or mild varus or those neutrally aligned. If anything, the functional outcome improved with increasing varus and there was a statistically significant association with an increased proportion of good/excellent results in varus knees at ten years.

This study does not demonstrate that alignment after UKR is inconsequential. Instead it demonstrates that the surgical approach which restores ligament tension to normal and thus restores pre-arthritic alignment, provided good functional outcomes and survival even though many patients had varus alignment post-operatively. This postoperative varus alignment is similar to the proportion of varus seen in the normal non-arthritic population (Figure 3). We believe that if pre-arthritic alignment was not restored it is likely that the outcome would be compromised. For example, medial collateral ligament (MCL) release would be required if knees with varus pre-arthritic leg alignment were corrected to neutral. If the release was done accurately and neutral alignment achieved this would result in overcorrection of the intra-articular deformity, which would alter knee kinematics and possibly compromise function. This might also result in incongruity of the lateral compartment and an increased risk of lateral OA. Furthermore, ligament release is unpredictable and the MCL could easily be overlengthened resulting in valgus alignment, lateral overload and OA progression. In addition, overlengthening of the MCL may result in ligament laxity which will increased the risk of bearing dislocation. Conversely many surgeons recommend under correction of the deformity and thereby leaving patients who had neutral pre-arthritic alignment in slight varus post operatively. This would result in loose ligaments which will compromise kinematics and, if the

ACL is lax, may result in patello-femoral joint overload and clinical problems with this joint. In addition loose ligaments may increase the risk of bearing dislocation. Post-operative varus alignment causes concern for TKR or fixed-bearing UKR as the increased medial loading may increase the risk of wear or loosening¹⁸⁻²⁰. The Oxford UKR has a fully congruent mobile-bearing which if implanted correctly has an average linear penetration rate of less than 0.02 mm/year¹⁶, it is therefore highly resistant to wear. In addition, load is transferred concentrically through the femoral component to the bearing, which then transmits compressive force onto the tibial component²¹. As a result there is predominantly compressive loading at the bone-implant interfaces with minimal shear, which makes the risk of loosening low. Although increased varus will increase medial loading, this has not resulted in an increased revision rate. There is a further concern with TKR that post-operative varus will lead to eccentric loading and rocking of the components which will induce tension at the bone-implant interface on the unloaded side of the component and loosening. With the Oxford UKR, whatever the alignment of the leg, the center of force is likely to be near the center of the components. Therefore, the bone-implant interface will be compressed and there should be no loosening. In this study there were no failures due to wear and the loosening rate was not related to leg alignment.

Our findings were similar to previous studies of alignment after the Oxford UKR. Gulati et al. found that there was a significant improvement in OKS with increasing varus alignment⁷. We found a similar trend, with increasing varus alignment associated with more patients achieving a good or excellent OKS at 10 years. However, we also found a trend towards a greater pre-operative OKS with increasing varus. It is interesting that there is some evidence to suggest that more active men tend to have more varus²². Pandit et al. found that there was no significant difference in risk of lateral compartment disease progression with different leg alignments²³. Whilst not significant, we found a trend of decreasing incidence of revision due to disease

progression with increasing varus. This may be a real observation because increasing varus would be expected to be associated with less lateral compartment OA. What is clear is that the outcome did not deteriorate with increasing varus. Therefore constitutional, **pre-arthritic varus**, which is usually caused by proximal tibia vara, even if marked, should not be considered to be a contraindication for Oxford UKR or a justification to do a high tibial osteotomy instead²⁴.

It is difficult to compare our results with fixed-bearing UKR, as the underlying surgical philosophy is different. They do not generally aim to restore normal ligament tension and thus pre-arthritic alignment. Following fixed-bearing UKR the best outcomes are achieved with mild varus^{8, 25}. Furthermore, it has been advocated that the optimal alignment is 1° to 4° varus so as to reduce the risk of disease progression in the lateral compartment⁸.

In this study there was a small (1%) subgroup of knees whose alignment was valgus. Although the number of knees (n=8) was too small for statistical comparisons they are an important subgroup. They were all women and presumably had pre-arthritic constitutional valgus. It is unclear why these patients develop medial compartment osteoarthritis but they clearly do. At the end of medial UKR it is a concern if the leg is in valgus. If this happens it is important that the surgeon examines the other leg as they will be reassured by finding constitutional valgus. Furthermore, in this situation, lateral OA does not seem to occur commonly, whereas it does if a knee without constitutional valgus has MCL damage during UKR and ends in valgus. None of these valgus knees failed due to disease progression, loosening or problems with the components at a mean follow up of 10.5 years. One was revised due to infection at 18 months. The main limitation of our study was that we do not routinely take post-operative long leg radiographs, as during the operation we are concerned about ligament tension not leg alignment. Our method of measuring alignment has been found to be accurate enough to categorise patients into the 5° alignment groups as its inter-observer error was 0.7° (SD 2).

228 Another limitation is that we did not have alignment measurement for 11% of cases. There is
229 however no reason to believe that, from an alignment point of view, they would be different
230 from those that had their alignment assessed. We did not routinely measure preoperative, pre-
231 arthritic and contralateral limb alignment.

232 In conclusion, these results support the ligament balancing and tensioning approaches used for
233 medial Oxford UKR, that restore knee kinematics and pre-arthritic alignment, which is
234 frequently mild and occasionally marked varus. Further, the results suggest that marked tibia
235 vara should not be considered to be a contraindication for UKR.

References

1. Riviere C, Iranpour F, Auvinet E, Howell S, Vendittoli PA, Cobb J, et al. Alignment options for total knee arthroplasty: A systematic review. *Orthop Traumatol Surg Res.* 2017 Nov;103(7):1047-56.
2. Bellemans J, Colyn W, Vandenuecker H, Victor J. The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. *Clin Orthop Relat Res.* 2012 Jan;470(1):45-53.
3. Shakespeare D, Ledger M, Kinzel V. Accuracy of implantation of components in the Oxford knee using the minimally invasive approach. *Knee.* 2005 Dec;12(6):405-9.
4. Goodfellow J, O'Connor JJ, Pandit H, Dodd CA, Murray D. *Unicompartmental Arthroplasty with the Oxford Knee* 2nd edition 2015.
5. Price AJ, Rees JL, Beard DJ, Gill RH, Dodd CA, Murray DM. Sagittal plane kinematics of a mobile-bearing unicompartmental knee arthroplasty at 10 years: a comparative in vivo fluoroscopic analysis. *J Arthroplasty.* 2004 Aug;19(5):590-7.
6. Emerson RH, Jr. Preoperative and postoperative limb alignment after Oxford unicompartmental knee arthroplasty. *Orthopedics.* 2007 May;30(5 Suppl):32-4.
7. Gulati A, Pandit H, Jenkins C, Chau R, Dodd CA, Murray DW. The effect of leg alignment on the outcome of unicompartmental knee replacement. *J Bone Joint Surg Br.* 2009 Apr;91(4):469-74.
8. Zuiderbaan HA, van der List JP, Chawla H, Khamaisy S, Thein R, Pearle AD. Predictors of Subjective Outcome After Medial Unicompartmental Knee Arthroplasty. *J Arthroplasty.* 2016 Jul;31(7):1453-8.
9. Kleeblad LJ, van der List JP, Pearle AD, Fragomen AT, Rozbruch SR. Predicting the Feasibility of Correcting Mechanical Axis in Large Varus Deformities With Unicompartmental Knee Arthroplasty. *J Arthroplasty.* 2017 Oct 05.

261 10. Goodfellow JW, Kershaw CJ, Benson MK, O'Connor JJ. The Oxford Knee for
262 unicompartmental osteoarthritis. The first 103 cases. J Bone Joint Surg Br. 1988
263 Nov;70(5):692-701.

264 11. Pandit H, Hamilton TW, Jenkins C, Mellon SJ, Dodd CA, Murray DW. The clinical
265 outcome of minimally invasive Phase 3 Oxford unicompartmental knee arthroplasty: a 15-year
266 follow-up of 1000 UKAs. Bone Joint J. 2015 Nov;97-B(11):1493-500.

267 12. Kennedy J, Matharu G, Hamilton T, Mellon S, Murray D. Age and outcomes of medial
268 meniscal-bearing unicompartmental knee replacement. The Journal of Arthroplasty. 2018.

269 13. Murray DW, Fitzpatrick R, Rogers K, Pandit H, Beard DJ, Carr AJ, et al. The use of
270 the Oxford hip and knee scores. J Bone Joint Surg Br. 2007 Aug;89(8):1010-4.

271 14. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clin
272 Orthop Relat Res. 1985 Sep(198):43-9.

273 15. Insall JN, Dorr LD, Scott RD, Scott WN. Rationale of the Knee Society clinical rating
274 system. Clin Orthop Relat Res. 1989 Nov(248):13-4.

275 16. Kendrick BJ, Simpson DJ, Kaptein BL, Valstar ER, Gill HS, Murray DW, et al.
276 Polyethylene wear of mobile-bearing unicompartmental knee replacement at 20 years. J Bone
277 Joint Surg Br. 2011 Apr;93(4):470-5.

278 17. National Joint Registry for England W, Northern Ireland and the Isle of Man. 13th
279 Annual Report. 2016.

280 18. Ritter MA, Davis KE, Meding JB, Pierson JL, Berend ME, Malinzak RA. The effect of
281 alignment and BMI on failure of total knee replacement. J Bone Joint Surg Am. 2011 Sep
282 07;93(17):1588-96.

283 19. Fang DM, Ritter MA, Davis KE. Coronal alignment in total knee arthroplasty: just how
284 important is it? J Arthroplasty. 2009 Sep;24(6 Suppl):39-43.

- 285 20. Collier JP, Mayor MB, McNamara JL, Surprenant VA, Jensen RE. Analysis of the
286 failure of 122 polyethylene inserts from uncemented tibial knee components. Clin Orthop Relat
287 Res. 1991 Dec(273):232-42.
- 288 21. Simpson DJ, Gray H, D'Lima D, Murray DW, Gill HS. The effect of bearing
289 congruency, thickness and alignment on the stresses in unicompartmental knee replacements.
290 Clin Biomech (Bristol, Avon). 2008 Nov;23(9):1148-57.
- 291 22. Yaniv M, Becker T, Goldwirt M, Khamis S, Steinberg DM, Weintroub S. Prevalence
292 of bowlegs among child and adolescent soccer players. Clin J Sport Med. 2006 Sep;16(5):392-
293 6.
- 294 23. Pandit H, Spiegelberg B, Clave A, McGrath C, Liddle AD, Murray DW. Aetiology of
295 lateral progression of arthritis following Oxford medial unicompartmental knee replacement:
296 a case-control study. Musculoskelet Surg. 2016 Aug;100(2):97-102.
- 297 24. Dettoni F, Bonasia DE, Castoldi F, Bruzzone M, Blonna D, Rossi R. High tibial
298 osteotomy versus unicompartmental knee arthroplasty for medial compartment arthrosis of the
299 knee: a review of the literature. Iowa Orthop J. 2010;30:131-40.
- 300 25. Vasso M, Del Regno C, D'Amelio A, Viggiano D, Corona K, Schiavone Panni A. Minor
301 varus alignment provides better results than neutral alignment in medial UKA. Knee. 2015
302 Mar;22(2):117-21.

Figure Legends

Figure 1: There was significant improvement with surgery with all groups attaining a high proportion of excellent or good Oxford Knee Score results at five and ten years post operatively. * indicates significant difference between groups

Figure 2: There was similar survival for all alignment groups.

Figure 3: A comparison of postoperative mechanical alignment (Hip Knee Ankle alignment) seen from this study and the normal population, as taken from Bellemans et al². There were more patients in marked varus from our centre, likely representing selection bias as patients in varus alignment are more likely to develop medial compartment osteoarthritis.