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■ EDITORIAL

40 years of the Oxford Knee

W. F. M. Jackson, K. R. Berend, S. Spruijt

From Nuffield Orthopaedic Centre, Oxford, United Kingdom

The Oxford Partial Knee (Zimmer Biomet, Bridgend, United Kingdom) has been used for the last four decades. Very few products make it to this milestone, not least in the world of medicine with the constant drive for innovation and improvement. The original design concept of John Goodfellow and John O'Connor, a fully congruent mobile meniscal bearing articulating with spherical femoral and flat tibial components, has remained unchanged.[1] That does not mean the 'Oxford' has not evolved. Over the course of 40 years, much work has been done in better understanding indications for its use,[2,3] improving instrumentation to allow accurate and more reproducible implantation through smaller incisions,[4] and design changes to improve fixation and durability of the components.[5]

In 1976, knee arthroplasty was still in its infancy. Engineers and surgeons were concerned with polyethylene wear with unconstrained designs, but as they increased congruity of the articulating surfaces, necessarily increased force was transmitted to the implant bone interface and high rates of loosening were observed.

Fairbank[6] had previously recognised the importance of the meniscus and noted its load-bearing properties. By conforming to the joint surfaces and moving with the knee, it could significantly increase the surface area over which load was transmitted, thereby reducing the pressure on the articular surfaces. Loss of this structure clearly led to abnormal forces in the knee and the development of medial compartment osteoarthritis.

Surgeon (Goodfellow) and engineer (O'Connor) met and set out to design a knee prosthesis that would minimise wear and reduce stresses through the implant bone interfaces. The Oxford Knee was introduced initially as a bicompartmental procedure. Fairly soon thereafter, anteromedial osteoarthritis was recognised as a path anatomical pattern,[7] and this has been increasingly recognised as the predominant pattern of osteoarthritis we treat.[8] Partial knee arthroplasty surgery was introduced.

The design philosophy of the Oxford has stood the test of time. Multiple studies have shown very low levels of polyethylene wear (0.01 mm/year) if no impingement is observed.[9] The implant has well-documented long-term survival rates, even into the second decade, showing the durability of the bone implant interfaces.[10] The technique allows the implant to be positioned balancing the ligaments and restoring their natural tensions. This restores the knee kinematics to pre-disease levels,[11] and leads to high function and better satisfaction than with conventional TKA designs.

There are, however, still concerns about partial knee arthroplasties in the orthopaedic community. Joint registries have shown higher rates of revision compared with conventional TKAs, and many suggest that their use should be limited.[12] This is despite the same registries showing better clinical results from partial knee arthroplasties than TKA.[13]

It has been well demonstrated from registry data that the thresholds for revision are different for partial knee arthroplasties and this goes partly to explain the increased revision rate.[14] It has also been well documented that surgical experience is important and much has been and continues to be done to educate surgeons in appropriate indications and optimum surgical technique.[15] There is good evidence that as surgeons undertake more partial arthroplasties as a percentage of their knee arthroplasty practice (up to 50%), their results improve.[16]

Data from joint registries not only show excellent clinical outcomes with more satisfied patients, they also show significantly lower complication rates with partial knee arthroplasty compared with TKA;[1,17] which should appeal to patients, surgeons and those who contribute towards the cost of health care.

The unique design of the Oxford knee continues to generate much interest. In this

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supplement we can see the Oxford being successfully implanted all over the globe with excellent ten-year data from the United States[18] and other European centres.[19]

As long-term survival of arthroplasty procedures have become more reliable, interest has been directed towards optimising knee function. The Oxford Knee has demonstrated excellent functional results,[13] but current patient-reported outcome measures may not be sensitive enough to appreciate these differences fully. The paper by Professor Cobb's group[20] from Imperial College, London shows that gait patterns can be returned to near normal levels. The Oxford technique of implanting the prosthesis with reference to the ligaments allows almost normal knee kinematics and is likely to contribute to the high function and satisfaction levels that are often reported.

There is still much to learn and things to be improved, and as a result, the Oxford Partial Knee will continue to be developed to benefit the patients we see.

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■ KNEE

Radiological Decision Aid to determine suitability for medial unicompartmental knee arthroplasty

DEVELOPMENT AND PRELIMINARY VALIDATION

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Aims

An evidence-based radiographic Decision Aid for meniscal-bearing unicompartmental knee arthroplasty (UKA) has been developed and this study investigates its performance at an independent centre.

Patients and Methods

Pre-operative radiographs, including stress views, from a consecutive cohort of 550 knees undergoing arthroplasty (UKA or total knee arthroplasty; TKA) by a single-surgeon were assessed. Suitability for UKA was determined using the Decision Aid, with the assessor blinded to treatment received, and compared with actual treatment received, which was determined by an experienced UKA surgeon based on history, examination, radiographic assessment including stress radiographs, and intra-operative assessment in line with the recommended indications as described in the literature.

Results

The sensitivity and specificity of the Decision Aid was 92% and 88%, respectively. Excluding knees where a clear pre-operative plan was made to perform TKA, i.e. patient request, the sensitivity was 93% and specificity 96%. The false-positive rate was low (2.4%) with all affected patients readily identifiable during joint inspection at surgery.

In patients meeting Decision Aid criteria and receiving UKA, the five-year survival was 99% (95% confidence intervals (CI) 97 to 100). The false negatives (3.5%), who received UKA but did not meet the criteria, had significantly worse functional outcomes (flexion $p < 0.001$, American Knee Society Score - Functional $p < 0.001$, University of California Los Angeles score $p = 0.04$), and lower implant survival of 93.1% (95% CI 77.6 to 100).

Conclusion

The radiographic Decision Aid safely and reliably identifies appropriate patients for meniscal-bearing UKA and achieves good results in this population. The widespread use of the Decision Aid should improve the results of UKA.

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Unicompartmental knee arthroplasty (UKA) provides significant benefits to patients, healthcare providers and healthcare payers.[1-3] Compared with total knee arthroplasty (TKA), patients undergoing UKA recover faster, achieve better functional outcomes, have a lower morbidity and mortality and report higher patient satisfaction.[1,2,4,5] Furthermore, UKA has been reported to be more cost effective than TKA in both the short- and long-term.[3,6,7] One concern with UKA however is the more variable long-term implant survival, with UKA having a higher overall revision rate than TKA.[1] This higher incidence of revision is multi-factorial, although it is known to be related to patient selection, surgical caseload, as well as a lower threshold for revision than with TKA.[8]

Despite meniscal-bearing UKA being appropriate in up to half the patients receiving treatment with knee arthroplasty, UKA is used in only 8% with large variation in usage between surgeons.[9] One proposed reason for this variation is the lack of recognition of indications for UKA. The primary indication for meniscal-bearing UKA is anteromedial osteoarthritis (AMOA), with spontaneous osteonecrosis of the knee (SONK) representing another important indication.[10] Patient factors including age, weight and level of activity; radiographic factors including chondrocalcinosis and lateral osteophytes; and operative factors including the presence of a chondral ulcer on the medial side of the lateral femoral condyle, have been demonstrated not to compromise outcomes

and are not considered to be contra-indications.[11-13] Therefore, identification of AMOA is crucial in determining suitability for meniscal-bearing UKA.

Patients are considered to have AMOA, and are therefore deemed suitable for meniscal-bearing UKA, if they meet each of the following criteria: bone-on-bone osteoarthritis (OA) in the medial compartment, retained full thickness cartilage in the lateral compartment, a functionally normal medial collateral ligament (MCL), and a functionally normal anterior cruciate ligament (ACL). In addition, they should have a patellofemoral joint (PFJ) that does not have severe damage laterally with bone loss, grooving and subluxation.[13-15] These criteria are assessed radiographically and are confirmed at operation. Additionally, practical considerations, such as the ability to flex the knee to 110° under anaesthetic to prepare the femoral condyle, need to be taken into account.

The criteria for AMOA are assessed using standing anteroposterior, valgus stress (in 20º flexion), true lateral and skyline radiographs. In the majority of patients, bone-on-bone arthritis in the medial compartment is demonstrated on the standing anteroposterior radiograph. However, in a proportion of knees, typically those with smaller anteromedial lesions, additional radiographs, such as a varus stress (in 20º flexion), or a standing flexed (at 20º, otherwise known as a Rosenberg or Schuss view)[16] radiograph is required. A valgus stress radiograph is required to demonstrate both that there is full thickness cartilage in the lateral compartment, and that the medial compartment opens fully, indicating that the MCL is functionally normal and not shortened. Stress radiographs should be performed with the knee in 20° flexion to relax the posterior capsule, and with the x-ray beam aligned parallel to the joint surface (which is best achieved by using a firm 6 inch triangular bolster behind the knee and tilting the x-ray tube 10º).[17] The functional status of the ACL is best determined from a true lateral radiograph, taken with the knee slightly flexed and the femoral condyles overlapping, as clinical evaluation of the ACL in the setting of OA can be misleading.[18,19] Where the ACL is functionally abnormal, or absent, the tibial erosion extends to the back of the tibial plateau and may be accompanied by posterior femoral subluxation. If the tibial erosion cannot be seen, or does not extend to the back of the tibia, there is a 95% chance that the ACL is functionally normal.[20] The PFJ should be assessed via a skyline radiograph with the knee in 30° flexion. Only in the presence of lateral bone loss with grooving and subluxation is there a contra-indication to meniscal-bearing UKA.[21]

The concept of a radiographic, atlas based, patient selection tool for UKA was first suggested by Oosthuizen et al[22] and stimulated by this, we have developed a radiographic Decision Aid, using the five evidence-based criteria outlined above, to improve patient selection for medial meniscal-bearing UKA. This study covers the development of the Decision Aid and investigates its sensitivity and specificity in predicting suitability for meniscal-bearing UKA in a consecutive cohort of patients undergoing knee arthroplasty (UKA or TKA) under the care of an independent surgeon (KRB) who was not involved in the development of the Decision Aid. The mid-term functional outcomes and implant survival in those knees where the Decision Aid advised meniscal-bearing UKA, and who underwent UKA were also investigated.

Materials and Methods

Development of the Decision Aid. An atlas-based radiographic Decision Aid, based on the five criteria that are required to be met to perform medial meniscal-bearing UKA for AMOA has been developed. The Decision Aid is divided into five sections, each assessing one of the five criteria, with radiographic view and exemplar radiographs provided that demonstrate when the criteria are met, as well as exemplar radiographs that demonstrate when the criteria are not met. Example radiographs of knees meeting the criteria to perform UKA were taken from a previously reported series[23] of meniscal-bearing UKA, in which the long-term functional outcomes and implant survival are known. Examples of knees not meeting the criteria are taken from a series of patients undergoing TKA during the same time period. Illustrative radiographs for each criterion were selected by consensus by the Decision Aid development team (TWH, HGP, DWM). Each criterion is assessed by way of a binary, yes-no, polar question with all criteria required to be met to perform meniscal-bearing UKA for an indication of AMOA.

Validation of the Decision Aid in an independent population. Between 01 January 2008 and 31 December 2008, 550 consecutive primary TKA or primary medial meniscal-bearing UKA were performed by an experienced UKA surgeon (KRB) at an independent centre not involved with the development of the Decision Aid. All patients signed an institutional review board approved general research consent allowing for retrospective review. The benchmark with which the Decision Aid was compared was actual treatment received, which was determined by an experienced UKA surgeon (KRB) based on history, examination, radiographic assessment including stress radiographs, and intra-operative assessment in line with the recommended indications as described by Goodfellow et al.[14]

Suitability for meniscal-bearing UKA was determined by assessing pre-operative radiographs using the radiographic Decision Aid with the assessor (TWH) blinded to the treatment received. A total of 12% of radiographs (n = 227 of 1962 radiographs) were re-assessed at three months by the primary assessor and also by an independent assessor (AC).

Patients were followed-up independently using a standard protocol. Functional outcomes were assessed using the American Knee Society Objective Score (AKSS-O), Functional Score (AKSS-F),[24] Lower Extremity Activity Scale (LEAS)[25] and the University of California, Los Angeles (UCLA) activity score.[26] Where patients had died, information about the status of their knee, and the presence of any

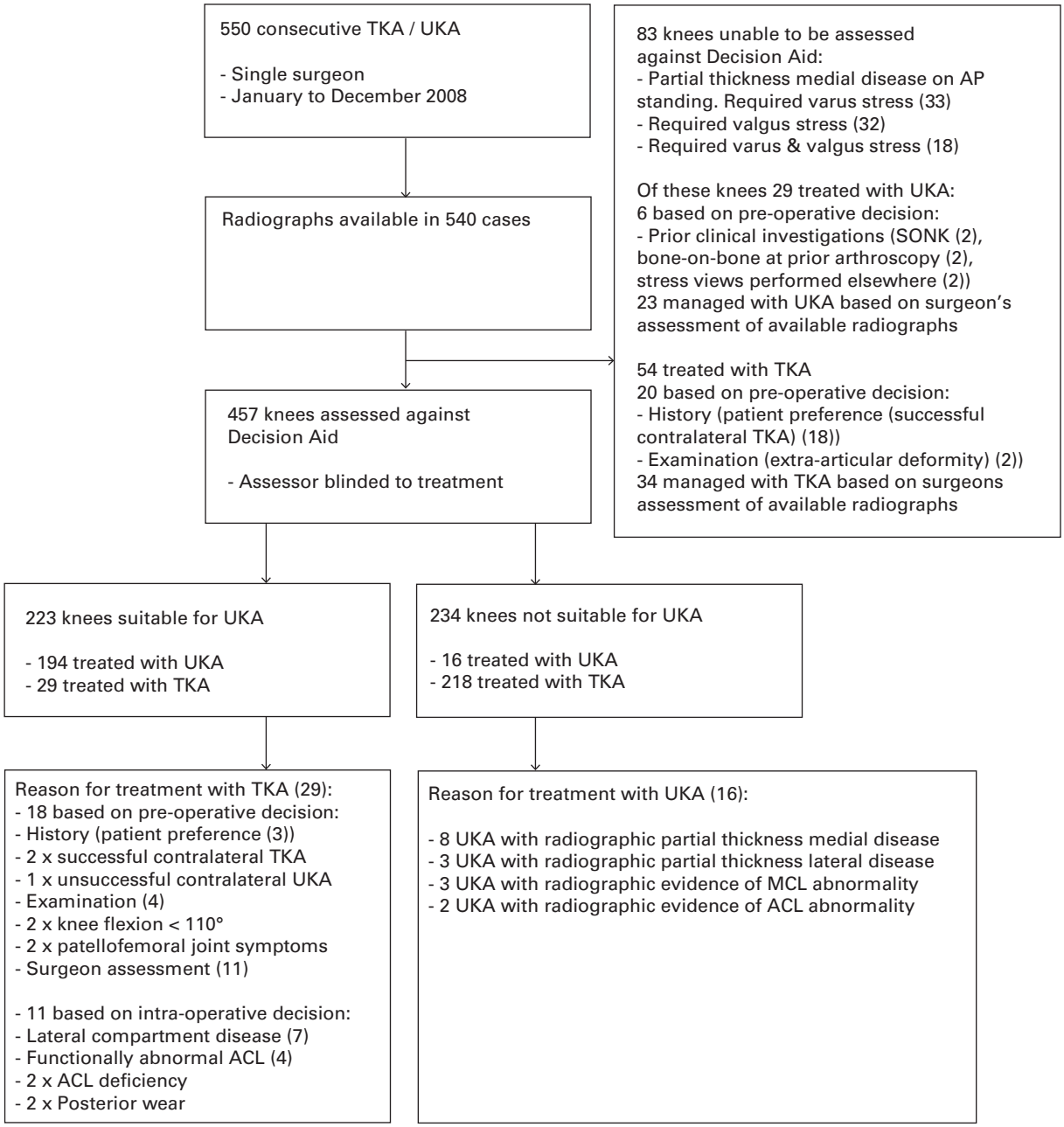

Fig. 1

Flowchart of study patients (UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty; AP, anteroposterior; SONK, spontaneous osteonecrosis of the knee; MCL, medial collateral ligament; ACL, anterior cruciate ligament).

further operation was obtained via primary and secondary care records as well as via patient's relatives where appropriate.

Performance of the Decision Aid was assessed by calculating the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy at identifying suitability for UKA. Performance was calculated based on radiographic assessment alone, and radiographic assessment combined with results of pre-operative findings from patient history, examination, prior clinical investigations and surgeon assessment. Patient history factors assessed included patient preference for implant type (i.e. successful contralateral arthroplasty) and history of inflammatory arthritis (UKA contraindicated). Patient examination factors included expected flexion < 110° which is required to prepare the femur at the time of operation. Prior clinical investigations included the results of a direct assessment of the joint at arthroscopy, as well as MRI demonstrating SONK. Other findings from MRI, including the status of the tibiofemoral joint and ACL, were not

Table I. Demographic details on knees undergoing surgery

	UKA mean (SD) (n = 239)	TKA mean (SD) (n = 301)	p-value
Time from surgery (yrs)	6.7 (0.4)	6.7 (0.5)	0.23
Follow-up (yrs)	3.9 (1.8)	2.8 (2.4)	< 0.001
Age (yrs)	63.2 (10.3)	65.8 (10.2)	0.01
% male	*41.0*	*40.2*	0.85*
Body mass index	31.9 (7.3)	33.3 (7.6)	0.02

* chi-squared test
UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty; SD, standard deviation

Table II. Functional outcomes in those undergoing unicompartmental knee arthroplasty (UKA) (Mann-Whitney U test)

	Decision Aid appropriate for UKA mean (SD)	Decision Aid not appropriate for UKA mean (SD)	p-value
Flexion			
Pre-operative	115.8 (8.8)	109.2 (11.9)	< 0.001
Post-operative	117.8 (7.8)	112.0 (11.4)	< 0.001
Change	2.1 (10.6)	2.7 (12.7)	0.65
Knee Society Objective Score			
Pre-operative	38.6 (13.9)	40.4 (18.9)	0.69
Post-operative (most recent)	87.7 (16.2)	90.2 (13.6)	0.63
Change	49.1 (21.4)	49.1 (22.7)	0.98
Knee Society Functional Score			
Pre-operative	57.5 (15.5)	51.7 (18.9)	0.001
Post-operative (most recent)	72.9 (22.7)	64.2 (25.1)	< 0.001
Change	15.3 (22.9)	12.2 (24.9)	0.12
Lower Extremity Activity Score			
Pre-operative	9.5 (2.8)	9.1 (2.9)	0.09
Post-operative (most recent)	9.9 (2.9)	9.7 (3.0)	0.44
Change	-8.1 (3.8)	-7.7 (3.7)	0.32
University of California, Los Angeles Score			
Post-operative (most recent)	6.2 (2.5)	5.3 (1.9)	0.04

SD, standard deviation

taken into account as these have not been demonstrated to affect patient outcomes and should not be used for patient selection.[27] Surgeon assessment included cases where the patient may have been suitable for UKA however a pre-operative decision was made by the surgeon to proceed with TKA.

Statistical analysis. To assess for differences in functional outcome between subgroups, non-parametric tests (Mann-Whitney U) were performed. A life-table analysis was performed to assess survival using implant-related re-operations, which included any re-operations in which components were changed, of which the bearing was replaced for dislocation, and any re-operations in which new components were inserted as the end point. Confidence intervals (CI) were calculated using the method described by Peto et al.[28] A p-value < 0.05 was considered to be statistically significant.

Results

Of the 540 knees (356 patients) in which radiographs were available, 239 (44%) underwent medial meniscal-bearing Oxford Phase 3 UKA (Zimmer Biomet, Warsaw, Indiana) and 301 (56%) underwent TKA. Complete sets of radiographs were not available in 83 knees (29 UKA, 54 TKA) which included two cases of SONK, leaving 457 knees for assessment against Decision Aid criteria (Fig. 1, Table I).

Based on the radiographic Decision Aid 49% (223) of knees were deemed suitable for medial meniscal-bearing UKA and 51% (234) were not suitable. There was excellent intra- (Cohen's kappa 0.90) and inter-observer (Cohen's kappa 0.85) agreement.

Of those 234 knees identified as not suitable for UKA, 40% (93 knees) did not meet one radiographic criteria, 38% (88 knees) did not meet two criteria, 22% (52 knees) did not meet three criteria and < 1% (one knee) did not meet four criteria. Of those knees that did not meet radiographic criteria, 46% (108 knees) had preserved medial compartment cartilage, 45% (105 knees) had posterior bone loss on their true lateral radiograph indicating ACL insufficiency, 67% (157 knees) had evidence of lateral compartment disease, 11% (25 knees) had evidence of MCL shortening and 16% (37 knees) evidence of bone loss with grooving to the lateral PFJ.

The functional outcomes of knees treated with UKA are outlined in Table II. In the 194 knees meeting Decision Aid criteria for UKA, who received UKA, there were four implant related re-operations (four patients) at a mean of 3.8 years (0.9 to 6.4). There was one case of instability

Table III. Life table analysis with 95% confidence intervals (CI) when Decision Aid was appropriate for unicompartmental knee arthroplasty (UKA) and UKA was performed

Follow-up (yrs)	Number at start	Revised	Withdrawn	At risk	Annual failure	Survival	95% CI	95% CI
0 to 1	194	0	7	190.5	0.000	100	100	100
1 to 2	187	1	7	183.5	0.005	99.5	98.4	100
2 to 3	179	1	25	166.5	0.006	98.9	97.2	100
3 to 4	153	0	57	124.5	0.000	98.9	97.0	100
4 to 5	96	0	19	86.5	0.000	98.9	96.6	100

Table IV. Functional outcomes in those undergoing total knee arthroplasty (TKA) (Mann-Whitney U test)

	Decision Aid not appropriate for UKA received TKA mean (SD)	Decision Aid appropriate for UKA received TKA mean (SD)	p-value
Flexion			
Pre-operative	109.2 (11.9)	110.9 (11.8)	0.49
Post-operative	112.0 (11.4)	110.2 (10.8)	0.43
Change	2.7 (12.7)	-1.1 (15.4)	0.18
Knee Society Objective Score			
Pre-operative	10.4 (18.9)	34.7 (10.9)	0.17
Post-operative (most recent)	90.2 (13.6)	90.9 (12.9)	0.91
Change	49.1 (22.7)	55.7 (17.4)	0.17
Knee Society Functional Score			
Pre-operative	51.7 (18.9)	56.0 (15.9)	0.24
Post-operative (most recent)	64.2 (25.4)	63.2 (20.4)	0.89
Change	12.2 (24.9)	4.8 (16.5)	0.45
Lower Extremity Activity Score			
Pre-operative	9.1 (2.9)	9.0 (2.4)	0.80
Post-operative (most recent)	9.7 (3.0)	9.9 (1.9)	0.49
Change	-7.7 (3.7)	-6.9 (2.9)	0.40
University of California, Los Angeles Score			
Post-operative (most recent)	5.3 (1.9)	5.6 (1.1)	0.57

UKA, unicompartmental knee arthroplasty

(0.9 years), one case of lateral compartment progression of arthritis (6.1 years), one case of femoral loosening associated with ACL deficiency (6.4 years) and one case due to an unknown cause with the revision operation performed elsewhere (2.0 years). The five-year survival in this cohort was 98.9% (95% CI 96.6 to 100) (Table III).

In 29 knees, the Decision Aid indicated suitability for meniscal-bearing UKA, however, TKA was performed (18 pre-operative decision, 11 intra-operative decision) (Fig. 1). Knees that were identified by the Decision Aid as suitable for UKA but underwent TKA had significantly worse post-operative flexion (110°, standard deviation (SD) 11° *versus* 118°, SD 8°; $p < 0.001$) and Knee Society Functional Scores (63.2, SD 20 *vs* 72.9, SD 23; $p = 0.04$) compared with knees managed with UKA who were identified as suitable. No other differences in functional scores were seen between these groups and no difference in functional outcome was detected between those knees identified as suitable for UKA that underwent TKA, and those identified as not suitable for UKA who were treated with TKA (Table IV).

There were no cases of failure in this group at a mean follow-up of 3.2 years (0 to 7) or in those knees (218 knees) not meeting Decision Aid criteria for UKA who were treated with TKA at a mean follow-up of 2.9 years (0 to 7).

In the 16 knees that did not meet Decision Aid criteria for meniscal-bearing UKA but received UKA, (Fig. 1) at a mean follow-up of 4.3 years (1 to 6) significantly lower flexion, AKSS-F and UCLA scores were obtained compared with those knees identified as suitable for UKA and were treated with UKA (Table II). However, they also had lower pre-operative functional scores, and no difference in improvement from baseline was observed. In this group there was one case of failure, progression of arthritis in the lateral compartment, at 2.3 years. The five-year survival (93.1%; 95% CI 77.6 to 100) in knees not suitable for UKA that underwent UKA was lower than those identified as suitable for UKA treated with UKA, however due to small numbers it was not possible to assess the significance of this difference.

The performance of the Decision Aid is outlined in Table V. A sensitivity analysis, performed to assess the role of skyline and stress radiographs in the evaluation for meniscal-bearing UKA, demonstrated a decrease in accuracy of 1% and 5%, respectively if these radiographs were not performed (Table VI).

Discussion

This study, which was undertaken in a cohort of patients operated on by a surgeon who was not involved with the

Table V. Performance of the Decision Aid in predicting suitability for unicompartmental knee arthroplasty (UKA)

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
Radiology alone	*92*	*88*	*87*	*93*	*90*
Radiology plus history	*92*	*89*	*88*	*93*	*91*
Radiology plus examination	*92*	*90*	*89*	*93*	*91*
Radiology plus surgeon assessment	*92*	*93*	*92*	*93*	*93*
Radiology plus results of prior investigations	*93*	*88*	*87*	*93*	*90*
Radiology plus all of above	*93*	*96*	*95*	*94*	*94*

History: patient preference for implant type (i.e., successful contralateral replacement)
Examination: clinical finding influencing implant selection (i.e., predicted flexion < 110° under anaesthetic, required to perform UKA)
Surgeon assessment: pre-operative decision made by the surgeon to proceed with total knee arthroplasty based on patient assessment
Prior investigations: prior arthroscopy demonstrating indication or MRI demonstrating spontaneous osteonecrosis of the knee

Table VI. Sensitivity analysis – skyline and stress radiographs

	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
All radiographic and clinical findings	*93*	*96*	*95*	*94*	*94*
Radiographic and clinical findings - no skyline radiograph	*93*	*94*	*93*	*94*	*93*
Radiographic and clinical findings - no stress radiograph	*88*	*90*	*90*	*89*	*89*

development of the Decision Aid (KRB), found the sensitivity and specificity of the radiographic Decision Aid at predicting suitability for meniscal-bearing UKA to be 92% and 88%, respectively. When the radiographic findings were combined with pre-operative factors that influence implant selection (i.e. patient request for TKA or flexion so limited that is was impossible to implant a UKA), the sensitivity and specificity increased to 93% and 96%, respectively. In those patients who met Decision Aid criteria for UKA and in whom UKA was performed excellent survival, 99% at five years (95% CI 96.6 to 100), and functional outcomes were achieved. Taken together this suggests that the Decision Aid is a useful tool for identifying appropriate patients for UKA in those who meet the criteria for joint arthroplasty.

The main concern about the Decision Aid is that there were a few false positives (2.4%) where the Decision Aid suggested a UKA should be done yet the surgeon did not perform a UKA. As a UKA was not undertaken, we cannot know what the outcome would have been had one been implanted, and therefore, have to assume that it might not have been good. Importantly, in all of these false positives the contraindication to UKA, such as a ruptured ACL, was readily identifiable during routine examination of the joint at the time of surgery. As inspection of the knee at the time of surgery is part of the surgical routine, with this stated to be necessary on the Decision Aid, we believe that it is safe to recommend the Decision Aid as the primary assessment for patient suitability for UKA. The only proviso being that the patient must be asked for consent for the possibility of a TKA, with TKA instrumentation being available should this be required.

In 3.5% of cases (16 knees) the Decision Aid did not support the use of a UKA, yet one was implanted. In these false negatives, although the clinical outcomes were satisfactory, the patients had significantly worse functional outcomes (flexion $p < 0.001$, AKSS-F $p < 0.001$, UCLA $p = 0.04$), and a lower implant survival 93.1% (95% CI 77.6 to 100) compared with those who had a UKA that was supported by the Decision Aid. This would suggest that the Decision Aid does identify the optimal patients for UKA, and that surgeons should be cautions when extending the indications beyond those recommended by the Decision Aid. The most common reason why the Decision Aid did not support a UKA that was implanted was that there was only partial thickness cartilage loss in the medial compartment and not bone-on-bone, as this subgroup of patients has previously been shown to have unpredictable results in independent studies.[29,30]

Sensitivity analysis, investigating the role of skyline and stress radiographs, highlighted the importance of performing stress radiographs when identifying suitability for meniscal-bearing UKA. In this series, if stress radiographs were not performed, the accuracy of the Decision Aid would be reduced by 5% (Table VI). In the absence of stress radiographs, 10% of knees would be inappropriately identified as suitable for meniscal-bearing UKA (PPV) as lateral compartment disease, demonstrated on valgus stress, would be missed. In addition, 11% of knees would be inappropriately identified as not suitable for meniscal-bearing UKA (NPV) due to medial bone-on-bone arthritis, demonstrated on varus stress, not being seen on standing anteroposterior radiographs. This highlights the importance of performing stress radiographs in the assessment of suitability for UKA, particularly as during visual intra-operative examination, it is often impossible to assess the cartilage thickness in the lateral compartment.

The sensitivity analysis demonstrated that not performing skyline radiographs only resulted in a 1% reduction in

the accuracy of the Decision Aid. This finding, combined with the fact that bone loss and grooving in the lateral part of the PFJ is readily identified at the time of operation, suggests that skyline radiographs could be omitted as they do not significantly influence patient selection. Furthermore, in the past skyline radiographs were not recommended. The reason why skyline radiographs, and to certain extent stress radiographs, have been included in the Decision Aid is different. The majority of surgeons currently restrict usage of UKA to cases where the lateral compartment and PFJ are virtually pristine, in order to avoid disease progression. This is incorrect, as providing the valgus stress radiograph shows full thickness cartilage laterally, and there is not severe arthritis in the lateral part of the PFJ seen on the skyline radiograph, this study demonstrates that excellent outcomes can be achieved. Indeed full thickness ulceration is commonly seen on the medial side of the lateral femoral condyle, as well as in the PFJ, and these factors have previously been demonstrated not to compromise outcomes.[12,15,21] If surgeons use the Decision Aid then they can complete an evidence-based document to determine whether a UKA is indicated. Furthermore, they can keep the document in the patient's record; thus, if their decision to perform a UKA is ever questioned, they will have evidence to show that it was correct.

The recommended indications for meniscal-bearing UKA are satisfied in about half of knees needing knee arthroplasty. In this study, which excluded lateral UKA, it was used and was supported by the Decision Aid in 42% of cases and very good results were achieved. There are also multiple published or presented series from surgeons who use UKA for about half of their knee arthroplasties in which the Oxford Phase 3 UKA has achieved a ten-year survival of around 95%.[23,31-33] Analysis of data from the National Joint Registry of England and Wales demonstrates that surgeons undertaking the Oxford UKA in less than 20% of knee arthroplasties, and in particular less than 10%, have a high revision rate, partly because the number is small, and partly because they are using the wrong indications.[1] At 20% and above the revision rate is acceptable, however, best results are achieved when surgeons undertake the Oxford UKA in about half of knee arthroplasties. Under these optimal circumstances the rate of re-operation of UKA is similar to that of TKA.[1] The use of the Decision Aid would ensure that surgeons use the recommended indications, and therefore achieve optimal results. Under these circumstances the patients will have all the advantages of UKA, including a faster recovery, lower morbidity and mortality compared with TKA, without the higher re-operation rate.

Importantly, this radiological Decision Aid can be implemented at all hospitals as it does not require specialist equipment or imaging modalities and enables surgeons to develop a patient management plan during a single clinic appointment. As it is simple it could not only be used by surgeons, but also referring physicians. Alternative techniques such as MRI have been proposed to assess suitability for UKA, however, they add additional time and cost, and the clinical relevance of these findings with respect to patient selection is yet to be clarified. Furthermore, Hurst et al[27] have demonstrated no difference in clinical outcomes following UKA in knees with MRI contraindications to UKA compared with those without questioning the clinical relevance of MRI findings.

There are certain limitations to this study. This study retrospectively analyses the mid-term outcome of patients treated by a single experienced UKA surgeon with longer-term data yet to be available. In the absence of a benchmark for patient selection for UKA a single experienced UKA surgeon series was chosen such that use of UKA was high and that UKA was being used in all appropriate cases in line with the current evidence. However, it is acknowledged that there may be variation even amongst experienced UKA surgeons in terms of their patient selection, and that the results seen in this high volume user series may not be generally applicable. Additionally, the association between high use of UKA and improved outcomes in patients undergoing this procedure has not been established to be causative. Whilst there is uncertainty as to whether increasing use will result in improved outcomes, optimising patient selection by ensuring that patients meet the indications of Goodfellow et al[14] would be expected to improve outcomes as the long-term results seen in published series that have adhered to these recommendations, have reported similarly good outcomes to those seen in this series.[31,33,34] Further work is required to establish the effect of introducing the radiological Decision Aid into general use to assess the true impact of this decision tool.

The radiological Decision Aid has a high sensitivity and specificity for predicting suitability for meniscal-bearing UKA and demonstrates that meniscal-bearing UKA can be used in around half of knees with excellent implant survival and functional outcomes. The Decision Aid is safe as, providing surgeons examine the knee at surgery, no patient should have an inappropriate UKA. The use of the radiological Decision Aid should optimise patient selection, which will minimise the revision rate of UKA and will allow more patients to benefit from UKA.

Supplementary material

An Appendix, the radiological Decision Aid, is available alongside the online version of this article at www.boneandjoint.org.uk

Take home message:

The use of the radiological Decision Aid optimises patient selection for meniscal-bearing UKA which in turn should minimise the revision rate and improve results allowing more patients to benefit from this procedure.

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T. W. Hamilton: Developed the radiological decision aid and study protocol, Collected primary data, Performed data analysis and interpretation, Wrote the manuscript.

H. G. Pandit: Developed the radiological decision aid and study protocol, Performed data analysis and interpretation, Wrote the manuscript.
A. V. Lombardi: Collected primary data, Critically appraised the manuscript.
J. B. Adams: Collected primary data, Critically appraised the manuscript.
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A. Clavé: Performed data analysis and interpretation, Critically appraised the manuscript.
C. A. F. Dodd: Developed study protocol, Critically appraised the manuscript.
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■ KNEE

Does location of patellofemoral chondral lesion influence outcome after Oxford medial compartmental knee arthroplasty?

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Aims

Medial unicompartmental knee arthroplasty (UKA) is associated with successful outcomes in carefully selected patient cohorts. We hypothesised that severity and location of patellofemoral cartilage lesions significantly influences functional outcome after Oxford medial compartmental knee arthroplasty.

Patients and Methods

We reviewed 100 consecutive UKAs at minimum eight-year follow-up (96 to 132). A single surgeon performed all procedures. Patients were selected based on clinical and plain radiographic assessment. All patients had end-stage medial compartment osteoarthritis (OA) with sparing of the lateral compartment and intact anterior cruciate ligaments. None of the patients had end-stage patellofemoral OA, but patients with anterior knee pain or partial thickness chondral loss were not excluded. There were 57 male and 43 female patients. The mean age at surgery was 69 years (41 to 82). At surgery the joint was carefully inspected for patellofemoral chondral loss and this was documented based on severity of cartilage loss (0 to 4 Outerbridge grading) and topographic location (medial, lateral, central, and superior or inferior). Functional scores collected included Oxford Knee Score (OKS), patient satisfaction scale and University College Hospital (UCH) knee score. Intraclass correlation was used to compare chondral damage to outcomes.

Results

All patients documented significant improvement in pain and improved functional scores at mid-term follow-up. There were four revisions (mean 2.9 years, 2 to 4; standard deviation (SD) 0.9) in this cohort, three for tibial loosening and one for femoral loosening. There was one infection that was treated with debridement and insert exchange. The mean OKS improved from 23.2 (SD 7.1) to 39.1 (SD 6.9); p < 0.001. The cohort with central and lateral grade 3 patellofemoral OA documented lower mean satisfaction with pain (90, SD 11.8) and function (87.5, SD 10.3) on the patient satisfaction scale. On the UCH scale, patients reported significantly decreased mean overall scores (7.3, SD 1.2 *vs* 9, SD 2.3) as well as stair climb task (3.5, SD 0.3 *vs* 5, SD 0.1) when cartilage lesions were located centrally or laterally on the PFJ. Patients with medial chondral PFJ lesions behave similar to patients with no chondral lesions.

Conclusion

Topographical location and severity of cartilage damage of the patella can significantly influence function after successful Oxford medial UKA. Surgeons should factor this in when making their operative decision, and undertake to counsel patients appropriately.

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Unicompartmental knee arthroplasty (UKA) is any accepted surgical option for treating anteromedial osteoarthritis (OA) of the knee with good long-term results and high patient satisfaction.[1-4] Patient selection for this procedure continues to be debated.[5-8] Recent literature has focused on the role of patellofemoral OA on outcomes after medial OA. Neither anterior knee pain nor radiologically-demonstrated medial patellofemoral joint degeneration is considered a contraindication to Oxford UKA (Biomet, Bridgend, United Kingdom).[9] However, management of severe arthritis of the lateral facet of the patella remains controversial and UKA is not considered to be an appropriate choice of surgery in this setting.[10,11] Some authors have argued that lateral patellar subluxation[12] is a poor predictor of outcome,

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irrespective of cartilage loss.[11,12] The suitability of plain radiographs in identifying patellar cartilage lesions is also debated, with some authors recommending MRI assessment of the patellofemoral joint in the presence of anterior knee pain[13] when selecting patients for medial UKA.

We believe that most surgeons offer UKA for predominantly anteromedial OA of the knee based on history, examination and radiographic assessment. We also believe that in the presence of obvious lateral tibiofemoral or lateral patellofemoral OA, surgeons err towards a total knee arthroplasty. There is however, a paucity of literature that will guide the surgeon with intra-operative decision making when faced with patellofemoral cartilage lesions during UKA for carefully selected anteromedial OA.

We hypothesised that the location and severity of the cartilage lesion involving the patellofemoral joint (PFJ) will influence functional outcome and patient satisfaction after medial UKA. Our aim was to investigate any link between medial and lateral PFJ cartilage lesions and its influence on satisfaction and outcome after medial UKA in order to help the surgeon with intra-operative decision making.

Patients and Methods

We prospectively reviewed a cohort of 100 consecutive UKAs in 100 patients (57 men, 43 women; mean age at surgery 69 years; 41 to 82) performed by a single senior surgeon (FSH) between 2002 and 2007. All patients underwent a medial Oxford UKA. Their mean body mass index (BMI) was 27.3kg/m^2 (22 to 36.4).

All patients had symptomatic medial knee pain with end stage OA on weight-bearing anteroposterior (AP) and lateral radiographs (Outerbridge grades 3 and 4[14] – bone-on-bone on standing radiographs). Patients also showed sparing of the lateral compartment on radiographs and this was confirmed on history and examination. None of the patients had radiographic evidence of grade 4 OA (Outerbridge) at the PFJ on the skyline view radiograph. Anterior knee pain in itself was not an exclusion criterion in the absence of grade 3 or 4 changes on plain radiographs.

UKA was not undertaken in the presence of gout or inflammatory arthritis. Pre-operative varus, fixed flexion more than 20° or a fixed varus deformity, were also excluded.

All patients received 1.5 g cefuroxime intravenously at induction and two further doses of 750 mg post-operatively. A tourniquet was inflated only during cementing of the prosthesis. A mini-incision medial-parapatellar approach was used in all cases. The patella was pushed/subluxed laterally, but not everted. Tibial and femoral preparation was undertaken according to the manufacturer's technical manual. The joint was carefully inspected to confirm a lack of lateral joint OA and to document the cartilage changes at the PFJ. Any cartilage loss at the PFJ was documented using the modified Outerbridge classification (0 to 4). Grade 0 was normal cartilage, grade1 was softening and swelling of the articular cartilage, grade 2 was a partial-thickness cartilage defect with fissures not reaching subchondral bone, grade 3 had fissures and fragmentation to subchondral bone, and grade 4 was exposed subchondral bone. The topographical location of the cartilage loss (trochlea or patella) was documented as medial, central or lateral and superior and inferior.

The mean hospital stay was 3.1 nights (2 to 6). Patients were followed-up at six weeks, six months and then annually. Weight-bearing AP, lateral and skyline radiographs were obtained at each follow-up visit.

Outcome measures. Pre-operatively and at follow-up, the following outcome measures were collected: Oxford Knee Score (OKS),[15] patient satisfaction scale,[16] anterior knee pain documented on visual analogue scale (VAS) and University College Hospital (UCH) knee score.[17] Outcome measures at the latest follow-up were used for analysis in this study. For comparison of outcomes, patients were divided into two groups; group 1 had severe chondral lesions (grade 3, 4) in the central or lateral PFJ; group 2 included all the other patients.

The senior author (FSH) undertook radiographic assessment at follow-up. Images stored on PACS electronically were reviewed and PACS measurement tools were used for all assessments. All patients had standing weight-bearing AP radiographs as well as lateral and skyline views. Alignment and progression of lateral or PFJ OA was documented. Aligment was measured on weight-bearing AP radiographs so as to document overall knee varus or valgus attitude, as well as implant varus or valgus position. Lateral radiographs were used to document tibial slope and femoral flexion. Skyline views were used to document PFJ OA.

Statistical analysis. All values were expressed as means, range and standard deviations (SD). Pre- and post-operative scores were compared using non-parametric (Mann-Whitney U test) measures. Correlation between chondral damage and functional scores were documented using Intraclass correlation coefficient (ICC) with 95% confidence intervals (CI). A p-value < 0.05 was considered to be statistically significant.

Results

The mean follow-up was ten years (8 to 13, median ten years). All patients documented significant improvement in pain and improved functional scores, which was sustained at the minimum eight-year follow-up. The OKS improved from 23.2 (SD 7.1) to 39.1 (SD 6.9); ($p < 0.001$).

A total of 52 knees had grade 3 or 4 cartilage lesions documented at surgery. In ten patients, no cartilage lesions were found at operation. On the patella there were 12 isolated lateral lesions (18 combined) and ten isolated medial defects (64 combined). On the trochlea, the distribution was as follows: 11 isolated central trochlea (combined 53); 12 isolated lateral lesions (combined 17); 12 isolated medial chondral lesions (combined 53). Table I provides the distribution of cartilage lesions in 100 patients.

A total of 18 patients reported severe anterior knee pain and persistent anteromedial pain. This resolved completely by 18 months' follow-up.

Table I. Distribution of cartilage lesions in our study population

Cartilage grade; location	n		
Patella	Grade 4	Grade 3	Grade 2
Medial	27	21	26
Lateral	4	8	18
Trochlea			
Central	11	18	35
Lateral	5	7	17
Medial	12	21	32

Table II. Comparison of mid-term outcomes in Lateral/ Central patellofemoral joint (PFJ) *versus* Grade 0/1/2 PFJ lesions. Mean values with standard deviations (Mann-Whitney U test)

	Grade 3/4 lateral/central PFJ		Grade 0/1/2 PFJ		
	Pre-operative	Post-operative	Pre-operative	Post-operative	p-value
OKS	23.7 (8.2)	39.6 (7.5)	24.2 (8.1)	40.0 (7.1)	p = 0.21
VAS	8.9 (1.2)	3.2 (1.1)	9.0 (1.2)	1.1 (1.5)	p = 0.42
Satisfaction (pain)	-	90 (11.8)	-	99 (5.1)	p = 0.01
Satisfaction (function)	-	87.5 (10.3)	-	99 (4.3)	p = 0.02
UCH Knee Score (performance function)	-	27.5 (5.3)	-	33 (6.1)	p = 0.01
UCH Knee Score (performance pain)	-	7.3(1.2)	-	9 (2.3)	p < 0.001
Step stair climb (performance function)	-	3.5 (0.3)	-	5 (0.1)	p < 0.001
Step stair climb (performance pain)	-	7 (1.1)	-	10 (1)	p < 0.001
Demographics					
n	29		58		
Mean age (range) yrs	70 (52 to 80)		67 (41 to 79)		
Gender	18 M/11F		36 M/22F		
Mean body mass index (range) kg/m^2	26 (22 to 35)		29 (21 to 32)		

OKS, Oxford Knee Score; VAS, visual analogue score for anterior knee pain; UCH score, University College Hospital score for anterior knee pain

There were four revisions in this cohort, three for tibial loosening and one for femoral loosening at a mean of 2.9 years (2 to 4, SD 0.9) from surgery. Radiographs did not show any malalignment of the implants in these four cases. There was one infection at six months that was salvaged with debridement and insert exchange. The revisions were not included in the review of chondral lesions and were excluded from the study.

Table II summarises the OKS, VAS and satisfaction score at minimum eight-year follow-up in those with intra-operative severe PFJ chondral damage (grades 3/4) in central and lateral compartments compared with those with mild or moderate PFJ OA (grades 0/1/2).

A statistically significant lower function on the stairs component of UCH score, overall UCH score, and higher pain measured using VAS and UCH knee score (pain component) were noted in those with grade 3/4 lateral PFJ changes (Table II). Figures 1 and 2 illustrate a lateral chondral lesion in the PFJ that was treated with a medial UKA. A high correlation ICC was noted between presence of chondral lesions and OKS (ICC 0.79, 95% CI 0.68 to 0.81), patient satisfaction (ICC 0.8, 95% CI 0.78 to 0.88), UCH knee score (ICC 0.79, 95% CI 0.68 to 0.84) and step stair function of UCH knee score (ICC 0.7, 95% CI 0.69 to 0.89).

Table III compares the OKS, VAS and satisfaction score at minimum eight-year follow-up in those with medial PFJ chondral damage in the cohort with no or minimal chondral damage documented intra-operatively. No significant difference was noted between patients who had medial lesions and those without any PFJ cartilage lesions or minimal cartilage damage (grade 1) found intra-operatively. Figures 3 and 4 illustrate an example of medial patellar cartilage lesion before and after medial unicompartmental arthroplasty.

Radiographic analysis at early follow-up confirmed satisfactory alignment and this was maintained at latest follow-up. Four patients presented after 24 months follow-up with symptomatic restriction of function and pain, and were noted to have implant loosening. None of the patients had pre-operative lateral compartment or PFJ OA and no progression was noted in this series at latest follow-up.

Discussion

In our study of a 100 consecutive UKA for predominantly anteromedial OA of the knee, we have shown improved patient satisfaction and functional outcome with Oxford UKA. We noted a high correlation between decreased patient satisfaction and presence of central or lateral grade 3 cartilage lesions. Presence of medial PFJ chondral lesions did not seem to influence the outcome. Patient-reported outcome measures (OKS), as well as functional task-based scores, confirmed this association.

Our study has several limitations. First it does not compare two cohorts of patients randomised to two groups based on their PFJ cartilage loss. This would require arthroscopic or MRI assessment of all patients and larger numbers. This is not our routine practice and we believe that patient selection for medial UKA should be based on his-

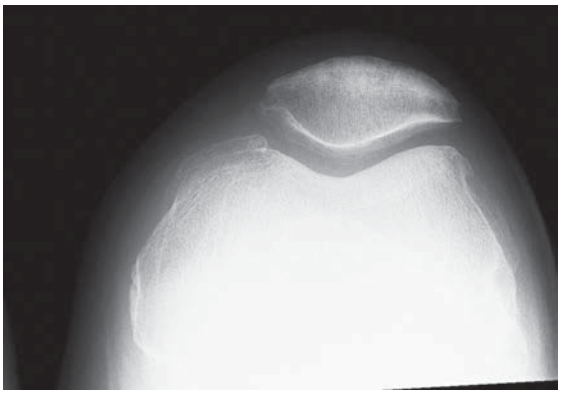

Fig. 1

Pre-operative radiograph of lateral chondral lesion in the patellofemoral joint that was treated with a medial unicompartmental arthroplasty.

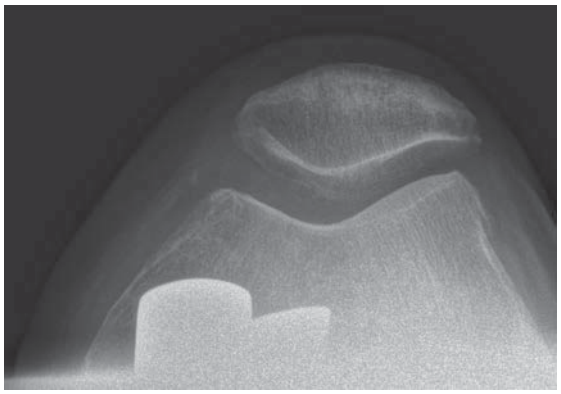

Fig. 2

Post-operative radiograph lateral chondral lesion in the patellofemoral joint that was treated with a medial unicompartmental arthroplasty at latest follow-up.

Table III. Comparison of mid-term outcomes in medial patellofemoral joint (PFJ) *versus* no or minimal PFJ lesions

	Medial PFJ		**Grade 0/1 chondral lesion**		
	Pre-operative	**Post-operative**	**Pre-operative**	**Post-operative**	**p-value**
OKS	23.2 (7.1)	40.0 (6.6)	24.0 (5.6)	40.0 (7.1)	p = 0.3
VAS	9.0 (1.5)	1 (0.5)	9.0 (1.2)	1.1 (1.4)	p = 0.6
Satisfaction (pain)	-	98 (10.6)	-	99 (7.3)	p = 0.5
Satisfaction (function)	-	99 (8.3)	-	99 (2.3)	p = 0.21
UCH Knee Score (performance function)	-	32.9 (7.3)	-	33.1 (5.1)	p = 0.3
UCH Knee Score (performance pain)	-	8.9 (1.0)	-	9 (1.3)	p = 0.4
Step stair climb (performance function)	-	4.9 (0.5)	-	5 (0.3)	p = 0.5
Step stair climb (performance pain)	-	9.1 (1.1)	-	10 (1)	p = 0.6
Demographics					
n	49		28		
Mean age (range) yrs	68 (48 to 79)		71 (59 to 80)		
Gender	28 M/21F		13M/15F		
Mean body mass index kg/m^2 (range)	30 (27 to 33)		29 (25 to 35)		

OKS, Oxford Knee Score; VAS, visual analogue score for anterior knee pain; UCH score, University College Hospital score for anterior knee pain

tory, examination and radiographic assessment. As shown by this study, arthrotomy and assessment of the knee compartments during surgery provide valuable information and help decision making before proceeding to UKA. Secondly, the patients with more severe lateral cartilage lesions may also differ in demographics and knee biomechanics to the cohort with normal PFJ cartilage. These factors need to be considered when interpreting the results of this study. However, despite these drawbacks, we believe that our study presents a pragmatic view of medial UKA outcomes and helps the surgeon with decision making, as well as pre- and post-operative patient counselling.

Other studies have highlighted the role of PFJ OA on outcome after medial UKA,[10,11,18] Our study adds to this knowledge and in addition has looked at the topographical location of the cartilage lesion as well as the grade of cartilage loss in greater detail. We also present the mid-term follow-up results compared with early results presented by most studies.[1-3] It is not clear from our study why lateral cartilage lesions are less well tolerated. However, this may be because medial UKA does not adequately address the biomechanics of the lateral patella. It may also be that presence of lateral PFJ lesions is an indicator for more extensive disease.

Our results demonstrated sustained pain relief and excellent knee scores at mid-term follow-up. The presence of patellar chondral lesions was associated with early persistent anterior knee pain, however, this seemed to resolve by the 18-month follow-up. Patients need to be given counselling in this regard. Presence of lateral or central PFJ chondral lesions was associated with decreased knee score and function. Beard et al[10] studied the influence of anterior knee pain or radiological evidence of PFJ OA on the patient-reported outcome of Oxford medial UKA. They found that patients with medial patellofemoral degeneration had a similar outcome to those without such degeneration. For some outcome measures patients with lateral patellofemoral degeneration had a worse score than those without, but these patients still had a good outcome. Pongcharoen and Reutiwarangkoon[18] compared patients with and without severe arthritis of the lateral facet of the patella following mobile-bearing UKA. They found that anterior knee pain, pain scores, and functional scores were not different between the two groups following a medial Oxford UKA. However, the knee scores of patients with severe arthritis of the lateral facet were worse than those in patients without severe arthritis of the lateral facet of the

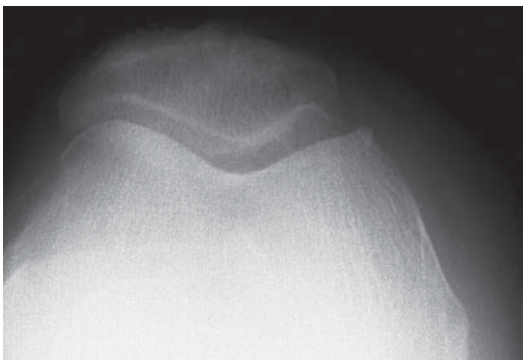

Fig. 3

Pre-operative radiograph of medial patellar cartilage lesion that was treated with a medial unicompartmental arthroplasty.

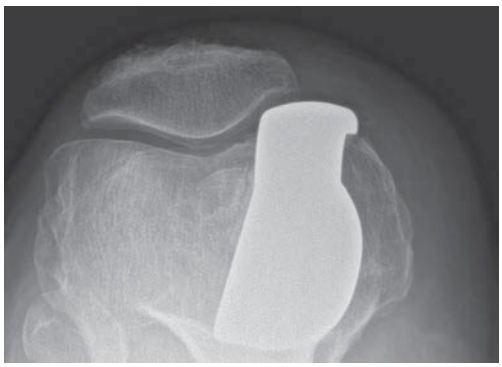

Fig. 4

Post-operative radiograph of medial patellar cartilage lesion treated with medial unicompartmental arthroplasty at latest follow-up.

patella. Song et al[11] compared the outcomes of patients with or without PFJ OA who underwent medial UKA. At median follow-up of 5.4 years (3.1 to 10.2), no significant inter-group difference was found in terms of anterior knee pain, Hospital for Special Surgery score, or range of movement. It is possible that their outcome scores were not sufficiently sensitive to demonstrate any difference in PFJ-specific knee pain. In our series, we noticed that the OKS was comparable, but UCH score and stair climb task demonstrated a significant difference. Munk et al[12] investigated the importance of PFJ degeneration and the location of pre-operative knee pain for the early favourable outcome of UKA. At one-year follow-up they observed that lateral subluxation of the patella and the pre-operative OKS was a predictor of poor outcome. Full-thickness cartilage loss at any location gave a similar outcome to that with a normal or near-normal joint surface. However, multiple surgeons were involved and routine skyline radiographs were not obtained and severe PFJ OA was not excluded from the series. Our study differs from that of Munk et al[12] in that a single surgeon performed all procedures and documented the cartilage lesions. Patients with end-stage PFJ OA were not included in our study group.

In conclusion, topographical location and severity of cartilage damage of the patella can significantly influence function after successful Oxford medial UKA. Surgeons should factor this in their decision making and advise patients appropriately.

Take home message:

Lateral PFJ cartilage lesions can negatively influence the outcome of medial UKA, however medial PFJ cartilage lesions are well tolerated.

Author contributions:
S. Konan: Data analysis, Writing the paper.
F. S. Haddad: Data collection, Data analysis, Editing the paper.

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■ KNEE

Gait comparison of unicompartmental and total knee arthroplasties with healthy controls

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Aims

To compare the gait of unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA) patients with healthy controls, using a machine-learning approach.

Patients and Methods

145 participants (121 healthy controls, 12 patients with cruciate-retaining TKA, and 12 with mobile-bearing medial UKA) were recruited. The TKA and UKA patients were a minimum of 12 months post-operative, and matched for pattern and severity of arthrosis, age, and body mass index.

Participants walked on an instrumented treadmill until their maximum walking speed was reached. Temporospatial gait parameters, and vertical ground reaction force data, were captured at each speed. Oxford knee scores (OKS) were also collected. An ensemble of trees algorithm was used to analyse the data: 27 gait variables were used to train classification trees for each speed, with a binary output prediction of whether these variables were derived from a UKA or TKA patient. Healthy control gait data was then tested by the decision trees at each speed and a final classification (UKA or TKA) reached for each subject in a majority voting manner over all gait cycles and speeds. Top walking speed was also recorded.

Results

92% of the healthy controls were classified by the decision tree as a UKA, 5% as a TKA, and 3% were unclassified. There was no significant difference in OKS between the UKA and TKA patients (p = 0.077). Top walking speed in TKA patients (1.6 m/s; 1.3 to 2.1) was significantly lower than that of both the UKA group (2.2 m/s; 1.8 to 2.7) and healthy controls (2.2 m/s; 1.5 to 2.7; p < 0.001).

Conclusion

UKA results in a more physiological gait compared with TKA, and a higher top walking speed. This difference in function was not detected by the OKS.

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Total knee arthroplasty (TKA) provides substantial improvements in quality of life for people with end-stage gonarthrosis.[1] However, only 75% of patients report satisfaction with the outcome,[2] a figure not improved by the use of newer implant designs.[3] The underlying premise of unicompartmental knee arthroplasty (UKA) is that the preservation of both cruciate ligaments, and of the remaining intact compartments of the knee, should result in more physiological knee kinematics, and hence better outcomes. However, large scale national joint registry (NJR) studies using patient reported outcome measures (PROMs) report only small differences between UKA and TKA.[4-6] Given that TKA continues to account for 90% of primary knee arthroplasties performed in the United Kingdom,[7] it is clear that the majority of surgeons are not persuaded by these small functional gains in the context of a higher reported rate of revision associated with UKA.[8]

PROMs may be unable to detect potential differences between UKA and TKA due to their inherent subjectivity and ceiling effect.[9] Gait analysis is an alternative, objective metric of arthroplasty performance, and previous studies have concluded that UKA patients exhibit a more normal gait pattern than TKA patients.[10-14] With the exception of one paper from our group,[15] these studies are limited by a reliance on self-selected walking speeds which make comparisons between participants unreliable.[16-18] Additionally, in common with most

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Table I. Subject demographics. Data are displayed as means (range)

	UKA	TKA	Healthy controls
Age (yrs)	65 (52 to 79)	68 (56 to 83)	32 (18 to 81)*
BMI (kg/m^2)	29 (24 to 34)	30 (24 to 39)	24 (17 to 35)*
Height (cm)	175 (167 to 184)	167 (151 to 186)	174 (153 to 198)
Ahlbäck Grade[1]	2 (1 to 3)	2 (1 to 3)	NA
Oxford Knee Score	44 (40 to 48)	43 (40 to 48)	NA

* Significant difference between the groups ($p < 0.05$)
BMI, body mass index; UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty

gait studies, they rely on the extraction of specific gait parameters from the large volume of data collected, thereby excluding potentially valuable information.[19]

Decision trees are a method of machine-learning for approximating discrete-valued functions – they are well suited to gait analysis in that they are useful for identifying regularities in large databases, they are robust to 'noisy' data, and have the added advantage that the resulting trees can be represented as sets of rules which are easily understood.[20] We set out to train a decision tree to discriminate between the gait of matched UKA and TKA patients, using all recorded gait parameters, at multiple velocities up to their maximum walking speed. By testing this decision tree with gait data from healthy controls, we wished to test the hypothesis that due to the joint preserving nature of UKA, normal healthy controls would be more likely to be classified as UKAs than TKAs.

Patients and Methods

A total of 145 participants were included in the study, which consisted of 121 healthy controls with no history of any disorder affecting their gait, 12 patients who had undergone TKA, and 12 who had undergone medial UKA. All arthroplasty patients had undergone their procedures for isolated radiographic medial tibiofemoral compartment arthrosis, and had completed at least 12 months of post-operative follow-up. TKA patients were matched to UKA patients for age, height, body mass index (BMI), and disease severity (assessed by two authors using Ahlbäck's classification,[1] Table I).[21] The UKAs were performed by one consultant surgeon (JPC), and the TKAs by another (RKS) – both surgeons perform more than 70 of these respective procedures each year. The implants used were the Oxford Phase III UKA (Zimmer Biomet, Bridgend, United Kingdom), performed using a minimally-invasive approach, and the Genesis II cruciate-retaining TKA (Smith & Nephew, London, United Kingdom). Post-operative component alignment was measured according to established methods, using digital short-knee radiographs.[22] A standardised post-operative rehabilitation regime was followed for all arthroplasty patients. All participants gave written informed consent, and ethical approval for the project was granted by the National Research Ethics Service (London-Camberwell St. Giles, REC Reference: 10/H0807/101) and Imperial College Healthcare NHS Trust (R&D Reference: 11/NE/0383).

Gait analysis was performed according to an established protocol, using a treadmill instrumented with force plates (Kistler Gaitway, Kistler Instrument Coporation, Amherst, New York).[15] After the patients familiarised themselves with the treadmill by walking at a comfortable speed for six minutes, this was increased in increments of 0.5 km/h until a maximum walking speed was reached (defined as the point at which the patient feels unsafe or would need to run if the speed was further increased).[23] Temporospatial gait parameters and vertical ground reaction force data were captured for 10s at each speed, with a sampling frequency of 100 Hz. All data were adjusted for body size using the methodology described by Hof.[24] Assessors were blinded to the type of operation performed. Oxford Knee Scores (OKS) were collected at the same time as gait analysis.[25]

A programme written in Matlab (Mathworks, Natick, Massachusetts) was used to implement an ensemble of trees (also known as a committee of trees) algorithm.[26] The gait data from UKA and TKA patients were used to train classification trees for each speed (4 km/h to 7.5 km/h); a total of eight trees comprised the ensemble. The following variables were considered: speed (m/s), incline (°), maximum force time (s), maximum force (N), first and second peak time (s), first and second peak force (N), mid-support time (s), mid-support force (N), peak ratio, active force time (s), active force (N), impulse (N*s), weight acceptance rate (N/s), push-off rate (N/s), contact time (s), gait cycle time (s), cadence (1/s), step time (s), double-support time (s), single limb stance time (s), base of support (cm), mean anteroposterior centre of pressure (cm), average mediolateral centre of pressure (cm), step length (cm), and stride length (cm).

The output of the decision tree was a binary prediction of whether these variables were derived from a patient that has undergone UKA or TKA (a representative tree can be seen in Figure 1). Gait data from healthy controls were then tested by the decision tree at each speed to predict whether they were most similar to a patient with a UKA or a TKA. The final decision was reached in a majority voting manner over all gait cycles and speeds.

Statistical analysis. This was performed with SPSS v.22 (IBM Inc., Armonk, New York). A paired *t*-test or one-way analysis of variance with Tukey *post hoc* analysis was used as appropriate. Kendall's W was used to determine reliability of Ahlbäck grading. Statistical significance was set at a $p < 0.05$. Results are reported as means (range).

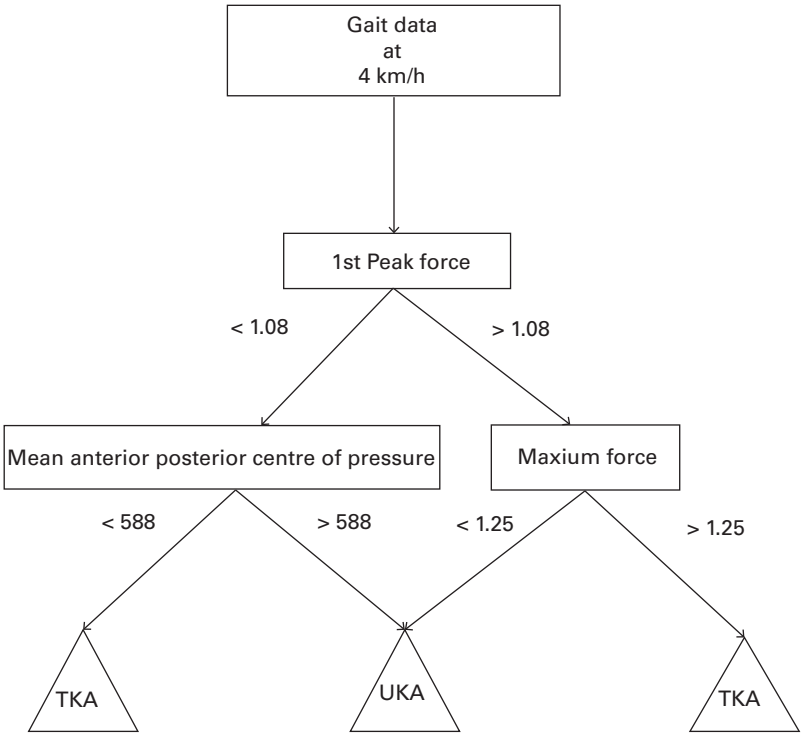

Fig. 1

Decision tree at 4 km/h trained with unicompartmental and total knee arthroplasty (UKA and TKA) data to classify gait in a binary fashion. First peak force and maximum force (normalised, therefore dimensionless), and mean anteroposterior centre of pressure (cm) values were selected by the algorithm. Gait data from each healthy control at 4 km/h was then processed by this decision tree, and classified as either a UKA or TKA. This was repeated at all eight walking speeds.

Results

There was no significant difference between the TKA and UKA groups for age ($p = 0.509$), weight ($p = 0.507$), height ($p = 0.08$), BMI ($p = 0.749$), OKS ($p = 0.077$) or Ahlbäck grade ($p = 0.474$). There was significant intra- ($W < 0.001$, $p = 1.0$) and inter-observer ($W = 0.125$, $p = 0.083$) agreement on Ahlbäck grading. The healthy control group was significantly younger ($p < 0.001$), and had a significantly lower BMI than both the arthroplasty groups ($p < 0.001$).

All components were well aligned radiographically:[22,27] mean femoral component alignment in the TKA group was 5° (2° to 7°) in the coronal plane, and 2° (0° to 5°) in the sagittal plane, with mean tibial component alignment 89° (87° to 90°) in the coronal plane, and 6° (3° to 8°) in the sagittal plane. In the UKA group, mean femoral component alignment was 3° (1° to 6°) in the coronal plane, and 2° (-2° to 5°) in the sagittal plane, with mean tibial component alignment 88° (86° to 90°) and 5° (3° to 7°) in the coronal and sagittal planes, respectively.

Of the 121 healthy controls, 111 (92%) were classified by the decision tree as a UKA, six (5%) as a TKA, and four (3%) were inconclusive.

First peak force (the maximum force measured during heel strike), weight acceptance rate (the slope of the force time curve during the loading phase, measured between a point at 10% of first peak force and a point at 90% of first peak force), and maximum force time (time from initial heel contact to the time of the absolute maximum force for an individual foot strike) were commonly selected by the decision tree to discern between the two arthroplasty groups. The force time curve in Figure 2 illustrates these differences.

Top walking speed was 1.6 m/s (1.3 to 2.1) in patients who had received TKA, which was significantly lower than the 2.2 m/s (1.8 to 2.7) achieved by patients with UKA ($p < 0.001$), and the 2.2 m/s (1.5 to 2.7) achieved by the healthy controls ($p < 0.001$, Fig. 3).

Discussion

In total, 92% of healthy controls were classified by the decision tree as a medial UKA, supporting the theory that preservation of both cruciate ligaments and the unaffected lateral tibiofemoral and patellofemoral compartments of the knee results in a more physiological gait compared with TKA. Inspection of the decision trees revealed that factors relating to initial heel strike were often used to discriminate between the two groups, with UKA patients having a faster weight acceptance rate and higher first peak force, similar to healthy controls. OKS in the UKA group were, on average, one point higher than those in the TKA group, but this difference was not statistically significant.

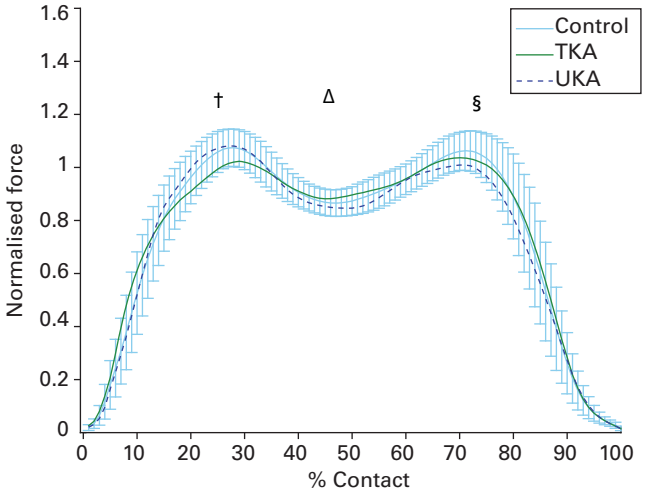

Fig. 2

Graph showing mean force time curve for unicompartmental and total knee arthroplasty (UKA and TKA) and healthy controls at 4 km/h. Healthy control data are displayed with 95% confidence intervals. † represents heel strike, Δ represents mid-stance, and § represents toe-off.

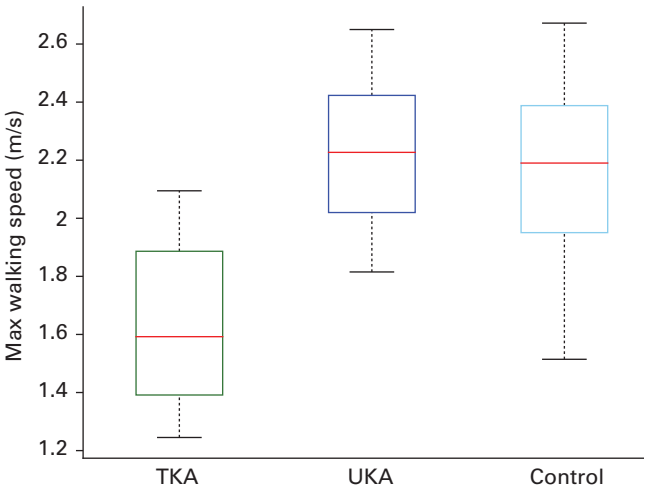

Fig. 3

Box-plots of top walking speeds showing median (red line), upper and lower quartiles (box), minimum and maximum values (whiskers). *Total knee arthroplasty (TKA) patients were significantly slower than unicompartmental knee arthroplasty (UKA) patients, and healthy controls ($p < 0.001$)

The strengths of this study include the use of an objective machine-learning algorithm to analyse the large volume of gait data acquired, avoiding the reporting bias normally introduced by extraction of specific gait variables for statistical testing. In reality, walking speed varies depending on the task at hand, and the use of a treadmill with integrated force-plates permits reproducible and comparable analysis of patients' gait at different speeds,[16] with gait data comparable with over-ground walking.[23] The UKA and TKA patients used to train the decision trees were well matched for pattern of arthrosis, radiological disease severity, age, height and BMI, thus reducing potential selection bias.

Limitations include the lack of randomisation, although the absence of clinical equipoise in the opinion of both surgeons made this impossible. Pre-operative gait data were not collected, and would have been useful to confirm that the UKA and TKA groups walked with a similar gait prior to operative intervention. The healthy controls were significantly younger, and had a lower BMI, than the arthroplasty patients, which may have affected their categorisation by the decision tree. The results of this study only apply to the two designs of prosthesis tested. In particular, the use of a cruciate-retaining TKA may affect the gait data obtained; fluoroscopic studies have demonstrated that cruciate-retaining TKAs have a paradoxical anterior movement of the femur on the tibia during flexion, which is improved in cruciate-substituting and medial pivot designs.[28-30] It is also uncertain whether an improved gait equates to higher patient satisfaction.

We used a novel machine-learning approach to analyse all recorded gait parameters, with a binary classification outcome that is easy to understand. Similar to data from NJR studies, there was only a small, one point, mean difference in OKS between the UKA and TKA groups.[4-6] This is in marked contrast to the gait analysis outcome, which was overwhelmingly (93%) in favour of UKA, and which reinforces the concern that current PROMs are unable to capture the true benefits of joint preserving procedures; objective gait data may be a superior measure.

Previous gait studies comparing TKA with healthy controls[11,31] consistently report loss of the normal biphasic flexion/extension moments around the knee, with an associated quadriceps avoidance gait – this is observed much less frequently in UKA.[10,14] These abnormal gait features have been attributed to the anteroposterior (AP) instability induced by anterior cruciate ligament (ACL) removal.[10] We found that altered loading during heel strike was often used as a discriminator between TKA and UKA, with a lower weight acceptance rate and a delayed, smaller first peak force, which mirrors the change in flexion/extension moments seen in both TKA and ACL-deficient patients (Fig. 4).[31,32]

We have previously found that UKA patients walk faster than TKA patients,[15] which is important because life expectancy significantly improves with every 0.1 m/s increase in top walking speed.[33] The decision tree approach used in the present study did not consider top speed as a variable when discriminating between implants (spatiotemporal and kinetic gait parameters were considered at each speed separately). However, analysis of the present data set confirms that the UKA patients walked significantly faster than their TKA counterparts (Fig. 3). The paradoxical AP movement seen during flexion following TKA[28,29] may account for this observation by limitation of mid-swing flexion, which impacts on stride length, and hence, walking speed.[34]

Compared with traditional 3D motion capture, an instrumented treadmill is a low-cost, quick and easy method of gait analysis. The results offer an objective

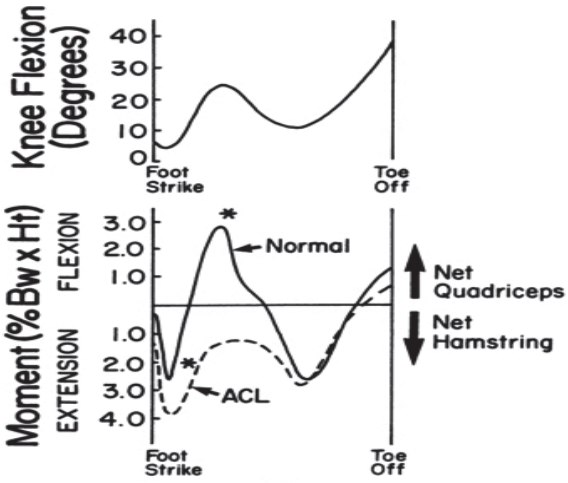

Fig. 4

During level walking by patients who had anterior cruciate (ACL) deficiency, an external extension moment about the knee persisted throughout most of the stance phase. In the presence of this moment, there is no need for activity of the quadriceps while the knee is near full extension. Normally, the necessary extension moment is produced by the quadriceps and is resisted by the anterior cruciate ligament. The asterisks identify the time during stance phase when the moments about knee of the control subjects and the patients were significantly different. Please see the original for the definitions of net quadriceps and net hamstring moments used in this study (reproduced from Berchuck et al[32] with permission).

assessment of function which is not captured using the PROMs collected by NJRs. A machine-learning approach to analysis of gait data is objective and simplifies data interpretation for clinicians. Of patients presenting with symptomatic knee arthrosis, 50% are suitable candidates for UKA.[35] The current study objectively demonstrates that for the two implants tested, UKA enables patients to have more normal gait compared with TKA, and patients should be aware of this when discussing their treatment options. Future studies will use the same approach to compare functional results between different implant designs.

Take home message:

Objective gait data is a valuable metric of function post-arthroplasty. When discussing UKA *versus* TKA, patients should be aware that UKA results in a more normal gait.

Author contributions:
G. G. Jones: Study design, Data analysis, Writing the paper.
M. Kotti: Study design, Data analysis, Writing the paper.
A. V. Wiik: Study design, Data collection, Writing the paper.
R. Collins: Data collection, Writing the paper.
M. J. Brevadt: Data collection, Writing the paper.
R. K. Strachan: Performed surgeries, Writing the paper.
J. P. Cobb: Performed surgeries, Writing the paper.

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■ KNEE

A survival analysis of 1084 knees of the Oxford unicompartmental knee arthroplasty

A COMPARISON BETWEEN CONSULTANT AND TRAINEE SURGEONS

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Aims

The aim of this to study was to compare the previously unreported long-term survival outcome of the Oxford medial unicompartmental knee arthroplasty (UKA) performed by trainee surgeons and consultants.

Patients and Methods

We therefore identified a previously unreported cohort of 1084 knees in 947 patients who had a UKA inserted for anteromedial knee arthritis by consultants and surgeons in training, at a tertiary arthroplasty centre and performed survival analysis on the group with revision as the endpoint.

Results

The ten-year cumulative survival rate for revision or exchange of any part of the prosthetic components was 93.2% (95% confidence interval (CI) 86.1 to 100, number at risk 45). Consultant surgeons had a nine-year cumulative survival rate of 93.9% (95% CI 90.2 to 97.6, number at risk 16). Trainee surgeons had a cumulative nine-year survival rate of 93.0% (95% CI 90.3 to 95.7, number at risk 35). Although there was no differences in implant survival between consultants and trainees (p = 0.30), there was a difference in failure pattern whereby all re-operations performed for bearing dislocation (n = 7), occurred in the trainee group. This accounted for 0.6% of the entire cohort and 15% of the re-operations.

Conclusion

This is the largest single series of the Oxford UKA ever reported and demonstrates that good results can be achieved by a heterogeneous group of surgeons, including trainees, if performed within a high-volume centre with considerable experience with the procedure.

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The Oxford Partial Knee (Zimmer Biomet, Swindon, United Kingdom) is a unicompartmental knee arthroplasty (UKA) with a fully congruent mobile bearing that is designed to reduce wear and was first introduced in 1982. The designer surgeons report cumulative prosthetic survival rates of 98% (95% CI 93 to 100) at ten years in their original series[1] and 96% (95% CI 92.5 to 99.5) ten-year survival for all implant related re-operations[2] for the third phase of prosthesis. A semi-independent series report similarly good outcomes of up to 95% (95% CI 90.8 to 99.3) at ten years.[3,4] However, independent single institution series from non-designer surgeons have produced less impressive results, with survival varying from between 83% to 90% at up to ten years.[5-7] In addition, the increasing availability of registry data collected from large numbers of surgeons with wide ranging experience with the prosthesis report results varying from 84.9% to 92% survival at ten years.[8-12] This has led to debate into the reasons for the variation in outcomes.[13] A number of studies have identified the importance of the numbers of procedures per annum performed by individual surgeons or centres undertaking partial knee arthroplasty, suggesting that centres and surgeons who perform this type of surgery more often have better survival results.[14,15] However, no previous study has investigated whether trainee surgeons, who may work in a high-volume centre but perform relatively few procedures themselves, can achieve good results.

The Nuffield Orthopaedic Centre is a high-volume teaching hospital unit performing approximately 300 UKAs each year. Surgeons in training perform a significant number of these procedures and we have never previously investigated the outcome of UKA performed by this group of surgeons and, in fact, the survival outcome of these patients has never been

Table I. Patient demographic details

Total number of patients/total number of knee implantations	949/ 1084
Mean age (yrs) (standard deviation)	66.5 (9.6)
Gender (%)	Male 461 (*48.6)*/female 488 (*51.4)*
Side (%)	Right 538 (*49.5)*/left 546 (*50.5)*
Unilateral/bilateral (%)	814 (*85.8)*/135 (*14.2)*
Surgeon grade (%)	Consultant 411 (*37.9*)/Trainee 673 (62.1%)
Deceased	63 patients (79 knees)

reported in the literature. Therefore, we have identified a cohort of patients with anteromedial knee arthritis[16] operated by a cross-section of non-designer surgeons at the Nuffield Orthopaedic Centre. The specific aims of this project were to compare the ten-year survival of the prosthesis when performed by consultants and surgeons in training.

Patients and Methods

We identified 1084 knees in 947 consecutive patients who underwent Oxford UKA for anteromedial knee arthritis between 1998 and 2008 at the Nuffield Orthopaedic Centre. None of these patients had been included in previous survival analyses from our institution.

All patients were selected for surgery using the Oxford indications for this procedure;[17] osteoarthritis producing severe or moderate pain that was unresponsive to non-operative care, bone-on-bone medial compartment changes, an intact anterior cruciate ligament and preserved full thickness cartilage in the lateral compartment. Age, obesity, chondrocalcinosis and patellofemoral degenerative changes were not contraindications to surgery.

Details of the operation were obtained from patients' notes and the hospital electronic records system. We identified those patients who were operated on by surgeons of all grades who were not part of the prosthesis design team. Surgeons were then categorised as consultants or trainees. The trainee group consisted of Specialist Registrars who were undertaking an arthroplasty rotation at our hospital as a part of their Higher Surgical Training and Fellows who were undertaking an arthroplasty fellowship. Although there was wide variation in the level of experience in the trainee group, the Fellows would be expected to have had greater exposure to knee arthroplasty procedures than the Specialist Registrars. However, neither of these groups would have had a significant prior exposure to UKA.

Patients were contacted by post and the status of the UKA was determined. If further surgery had been performed in a hospital other than our centre, that unit was contacted and details of the surgery were requested. A formal review of the electronic operation record was performed for revision surgery at our hospital for each patient. If revision surgery was found to have taken place at the Nuffield Orthopaedic Centre, the notes were obtained and reviewed for the details of the procedure.

Patients who did not respond to the initial postal questionnaire were sent two further questionnaires by post and then were contacted by telephone. If no response regarding the status of the knee was received, their primary care physician was contacted and asked to review the primary care notes for any evidence of further surgery on the knee. If no data were available from the primary care physician, the patient was considered as lost to follow-up and the prosthesis was presumed to fail at either the day after the operation, or the day after the last date when the prosthesis was known to be *in situ*.[18]

Statistical analysis. Descriptive statistics were used to explore data. Cross-tabulation and the Pearson chi-squared tests were used for categorical data relating to revision rates between operations performed by consultants and trainees. All cause revision (defined as the removal or exchange of any part of the prosthetic components) was used as the endpoint for best-case survival analysis.[19] A life table was constructed for each endpoint definition and survival rates up to ten years were determined. Patients who were lost to follow-up were treated as revisions. Life table survival plots were produced and a log-rank test was used to compare the two groups at nine years post-operatively, so that the number at risk at nine years would be a minimum of ten in each group. Statistical significance was defined as a p-value < 0.05. Statistical analysis was performed using STATA version 12 (Statacorp, College Station, Texas).

Results

Patient demographic details are reported in Table I. The mean patient age at time of surgery was 66.5 years (standard deviation (SD) 9.6). There was an almost equal distribution between male and female patients and side of operation. In all 814 patients had unilateral Oxford UKAs, and in 135 patients there were bilateral Oxford UKAs (although not simultaneously inserted). In total, 77 trainees performed 673 procedures (62.1%), with 13 consultants performing the remaining 411 (37.9%).

A further breakdown of cases performed by trainees stratified by their experience level and whether or not they were supervised by a consultant who was scrubbed at the time of surgery is presented in Table II. A total of 289 UKAs were performed by 49 Specialist Registrars, 159 (55%) of whom were directly supervised by a consultant. A total of

Table II. Number of procedures performed by Fellows and Specialist Registrars with corresponding supervision and failure rate

Experience level	Total number of UKA procedures performed	Mean number of procedures performed (range)	Number of supervised procedures with consultant scrubbed (%)	Number of failures (% of entire trainee cohort)
Specialist Registrar (n = 49)	289	5.9 (1 to 41)	159 (*55*)	14 (*2.1*)
Fellow (n = 28)	384	13.7 (1 to 56)	162 (*42.2*)	17 (*2.5*)
Total trainee cohort (n = 77)	673	8.7 (1 to 56)	321 (*48*)	31 (*4.6*)

UKA, unicompartmental knee arthroplasty

Table III. Summary of revision procedures

Reason for revision	n (% incidence)	Procedure	n
Aseptic loosening	12 *(1.1)*	Revision toTKA/UKA	10/2
Lateral progression	13 (*1.2*)	TKA/Lateral UKA	8/5
Infection	7 (*0.6*)	DAIR with bearing exchange/TKA	3/4
Unexplained pain	5 *(0.4)*	TKA	5
Bearing dislocation	7 (*0.6*)	Bearing exchange only/conversion to TKA/conversion to fixed bearing tibia UKA	4/2/1
Fracture of tibia	1 (*0.1*)	TKA	1
Unknown*	1 *(0.1)*	TKA	1
Total	46 (4.2)		46

* Reported by Primary Care Physician
TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty; DAIR, debridement antibiotics and implant retention

384 UKAs were performed by 28 Fellows, 162 (42.2%) of whom were directly supervised by a consultant. The median number of UKAs performed by Specialist Registrars was 3 (1 to 41) whilst the median number of procedures performed by Fellows was 7 (1 to 56).

The mean follow-up was 5.2 years (1 to 12.7, SD 2.2). A total of 79 patients (7.3%) had died. Three patients (0.3%) were unable to be contacted and were therefore declared lost to follow-up. Of the remainder, in 936 (86.3%) the status of the knee was determined from the patient. In 143 (13.2%) the status was determined from the primary care physician.

There were 46 revisions (4.2%), the details of the indication are provided in Table III. A number of UKAs required further surgery without revision of any prosthetic components; 15 underwent exploratory arthroscopy with no further action, three underwent washout of wound and evacuation of haematoma, three manipulation under anaesthetic, one excision of wound neuroma and one open exploration for impingement.

A total of 15 revisions occurred in the consultant group with a revision rate of 3.6%, compared with 31 and 4.7% in the trainee group. There was no significant difference in failure rate between the consultant and trainee group (p = 0.62, Pearson chi-squared). The mean time to revision for the consultant group was 3.8 years and 3.1 years for the trainee series. Comparing the pattern of failure between groups showed that all revisions for dislocation occurred in the trainee group.

Further subanalysis of the trainee group (Table II) showed that there were 14 failures in UKAs performed by Registrars (accounting for 2.1% UKAs performed by trainees) compared with 17 failures in UKAs performed by Fellows (accounting for 2.5% UKAs performed by trainees). There was no significant difference in failure rate between Registrars and Fellows (p = 0.89, Pearson chi-squared).

Analysis of failure rates in the trainee group showed that 17 of the failures occurred in cases where a consultant was scrubbed compared with 14 cases where the trainee was operating independently. This difference was not statistically significant (p = 0.65, Pearson chi-squared). The failure rate within the trainee group was also analysed based on the number of UKAs performed. Trainees who had performed fewer than ten UKAs had a failure rate of 5.1% (9 out of 193 UKAs) compared with a failure rate of 4.7% (22 out of 489 UKAs) in those who had undertaken more than ten UKAs. This difference was not statistically significant (p = 0.51, Pearson chi-squared).

The ten-year cumulative survival rate for revision or exchange of any part of the prosthetic components was 93.2% (95% CI 86.1 to 100, number at risk 45) with the survival table shown in Table IV. Consultant surgeons had a nine-year cumulative survival rate of 93.9% (95% CI 90.2 to 97.6, 3.7, number at risk 16) and trainee surgeons had a cumulative nine-year survival rate of 93.0% (95% CI 90.3 to 95.7, number at risk 35) (Fig. 1). There was no difference in survival between groups (p = 0.30, log rank).

Discussion

This ten-year survival analysis of 1084 knees from the Nuffield Orthopaedic Centre, but not including procedures performed by the designer surgeons, represents the largest single series of Oxford UKAs in the literature. None of the patients in this series have been included in previous reports of outcome for the Oxford UKA. We report a cohort of 1084 UKAs inserted by 90 different surgeons of different grades. Using revision of any component as failure, we identify a predicted survival of 93.2% (95% CI 86.1 to

Table IV. Life table for whole cohort

Post-operative yr	n	Failures	Successes	Number at risk	Cumulative survival %	95% CI
1	1084	13	4	1082.0	99.0	99.4 to 99.6
2	1067	6	17	1058.5	98.2	97.4 to 99.0
3	1044	8	134	977.0	97.4	96.4 to 98.4
4	902	6	198	803.0	96.7	95.5 to 97.9
5	698	8	176	610.0	95.4	93.8 to 97.0
6	514	3	106	461.0	94.8	92.8 to 96.8
7	405	4	148	331	93.7	91.2 to 96.2
8	253	1	126	190	93.2	89.7 to 96.7
9	126	0	59	96.5	93.2	88.3 to 98.1
10	67	0	44	45.0	93.2	**86.1** to **100**
11	23	0	23	11.5	93.2	79.1 to 100

CI, confidence interval

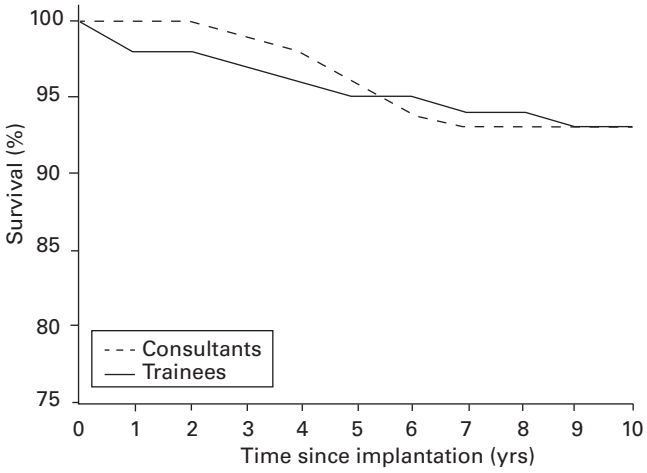

Fig. 1

Graph showing cumulative survival of implants over ten years, comparing consultants and trainees.

100, number at risk 45) at ten years, with 46 requiring revision of one component or more. There was no difference in predicted survival at nine years between those procedures performed by consultants and those performed by trainees.

Although previous studies have evaluated the impact of surgeon grade on the long-term outcome of total hip[20,21] and total knee arthroplasty,[22] to our knowledge, this is the first study which attempts to evaluate the long-term outcome of UKAs performed by trainees. In keeping with the aforementioned studies, our findings suggest that with appropriate training and supervision, trainee surgeons can achieve similar results to experienced consultants during UKA.

In 1998 Murray, Goodfellow and O'Connor[1] reported a cumulative survival rate at ten years of 98% (95% CI 93 to 100) for a cohort of 143 knees undergoing the Oxford UKA. Subsequently, in a cohort of 1000 patients at ten years for the third phase prosthesis, they described a 96% (95% CI 92.5 to 99.5) cumulative survival rate.[2] In a series from Skovde, Price, Waite and Svärd[3] described ten- and 15-year survival of 95% (95% CI 90.8 to 99.3) and 94% (95% CI 83.1 to 100), respectively, with successful clinical results at ten years. However, these results have not been reproduced in all series and in particular joint registers have shown higher rates of revision.[8-10] The Swedish Knee Arthroplasty Registry has previously identified that the numbers performed by a centre can significantly affect the survival of partial knee arthroplasty, with those centres performing over 23 a year outperforming centres undertaking fewer.[21] More recently, published data have been identified which reveal for individual surgeons performing more than approximately 15 partial knee arthroplasties a year, the revision rates are improved compared with those undertaking fewer.[15] As a result, this has raised issues about the minimum number of procedures that should be performed a year if surgeons undertake partial knee arthroplasty.[23,24] In light of this, the training of younger surgeons to undertake partial knee arthroplasty becomes an issue. To our knowledge this is the first study to compare directly the long-term survival results from consultants and trainees within a single unit and we have demonstrated that good results can be achieved from multiple surgeons of differing potential ability and experience. Consistency has been achieved in that all procedures were performed in a recognised centre of excellence for the procedure performing well over 23 UKAs per year. The centre has well-established training, focusing on indications and insertion techniques. This enables trainees to undertake independent UKA procedures with seemingly no detrimental effect on revision rates, as demonstrated by the findings of the current study. In addition, theatre personnel are familiar with the procedure and ward rehabilitation and physiotherapy post-operatively follows a structured and established course. The lack of difference in failure rates between trainees performing fewer than ten UKAs and those performing more than ten UKAs may be explained by the multi-disciplinary expertise of the unit as a whole and the training philosophy. Similarly, as previously suggested,[14] indications for revision procedures in this hospital may be different for others, leading to a lower revision of prosthetic components. While trainees are likely to be still on the learning curve of expertise for performing this procedure, the current study indicates that despite this, they can still expect to have good survival.

When analysing prosthetic failure modes within this study, the two most common overall causes of revision, namely aseptic loosening and lateral compartment progression, were similar to those found in the existing literature.[25] However, a closer look at the bearing dislocation rate shows that all seven dislocations (15% of all re-operations) occurred following operations performed by trainees. This mode of failure is often regarded as a marker for technical proficiency during the Oxford UKA due to factors such as damage to the medial collateral ligament, impingement from osteophytes, flexion/extension gap imbalance and component malpositioning which results in a wide gap between the tibial and femoral components.[26-28] Our teaching philosophy is to emphasise the risk of such errors to our trainees – this is reflected by the very low overall dislocation rate of 0.6% in this series which compares favourably with a pooled dislocation rate of 1.5% reported for the Oxford UKA in a recent systematic review.[29] Furthermore, the failures in the current study, which tended to occur within the first two years of surgery, did not adversely affect the long-term survival when comparisons were made between trainees and consultants.

This study has some strengths and weaknesses. This series is the largest series of Phase III Oxford medial UKA to ever be reported from a single centre. Despite being a retrospectively identified cohort, the loss to follow-up in this series is only 0.3%. In 13.2% of all cases, status details were obtained from their primary care physician, however, this is felt to be acceptable given the length of follow-up and volume of cases. It would have been desirable to undertake a similar analysis for total knee arthroplasties performed at our institution for comparison, however, these data were not available and the main focus of the study was to determine outcome and survival in UKAs in a high-volume centre with expertise in UKA training. A major strength of the paper is the collection of data across the full spectrum of surgeons performing Oxford medial UKA at the centre, rather than a few highly selected surgeons. This means the results may represent a truer reflection of the success within the population.

In conclusion, this is the largest ten-year follow up of the Oxford UKA ever reported. Whilst we are aware of the issues of bias given its origin from the inventing centre, this series involves over 90 individual surgeons of varying experience and expertise, with none being part of the designer team. The survival of 93.2% at ten years is likely to result from a standardised approach to surgery with strict indications for the operation and a uniform threshold for revision. Within this framework of care, good results with the Oxford UKA can be achieved by a heterogeneous group of consultant and trainee surgeons.

Take home message:

This is the largest ten-year follow up of the Oxford UKA ever reported. Within this framework of care, good results with the Oxford UKA can be achieved by a heterogeneous group of Consultant surgeons and trainees.

Author contributions:

N. Bottomley: Study protocol, Data collection, Data analysis, Writing the manuscript.
L. D. Jones: Study protocol, Data collection, Data analysis, Writing the manuscript.
R. Rout: Study protocol, Data collection, Critical appraisal of manuscript.
A. Alvand: Study protocol, Data analysis, Writing the manuscript.
I. Rombach: Data analysis, Critical appraisal of manuscript.
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■ KNEE

Early outcomes of twin-peg mobile-bearing unicompartmental knee arthroplasty compared with primary total knee arthroplasty

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Aims

Since redesign of the Oxford phase III mobile-bearing unicompartmental knee arthroplasty (UKA) femoral component to a twin-peg design, there has not been a direct comparison to total knee arthroplasty (TKA). Thus, we explored differences between the two cohorts.

Patients and Methods

A total of 168 patients (201 knees) underwent medial UKA with the Oxford Partial Knee Twin-Peg. These patients were compared with a randomly selected group of 177 patients (189 knees) with primary Vanguard TKA. Patient demographics, Knee Society (KS) scores and range of movement (ROM) were compared between the two cohorts. Additionally, revision, re-operation and manipulation under anaesthesia rates were analysed.

Results

The mean follow-up for UKA and TKA groups was 5.4 and 5.5 years, respectively. Six TKA (3.2%) *versus* three UKAs (1.5%) were revised which was not significant (p = 0.269). Manipulation was more frequent after TKA (16; 8.5%) *versus* none in the UKA group (p < 0.001). UKA patients had higher post-operative KS function scores *versus* TKA patients (78 *versus* 66, p < 0.001) with a trend toward greater improvement, but there was no difference in ROM and KS clinical improvement (p = 0.382 and 0.420, respectively).

Conclusion

We found fewer manipulations, and higher functional outcomes for patients treated with medial mobile-bearing UKA compared with TKA. TKA had twice the revision rate as UKA although this did not reach statistical significance with the numbers available.

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Controversy exists about the benefits of unicompartmental knee arthroplasty (UKA) *versus* total knee arthroplasty (TKA) for the treatment of isolated arthritic degeneration of the medial compartment of the knee. Advocates of UKA cite it is less invasive compared with TKA,[1] with reduced mortality and fewer complications.[2] UKA preserves undamaged structures, including the cruciate mechanism, which provides more natural kinematics,[3] and the patellofemoral joint, which gives more normal contact force and pressures.[4] Studies have shown that patients achieve a greater range of movement (ROM) after UKA,[5-12] and better perceived feel and function, particularly with demanding activities such as stair climbing.[13-18] Advocates for TKA over UKA for treatment of isolated medial osteoarthritis cite higher revision rates for UKA in large registry studies.[19-21] Our centre has previously compared patients undergoing primary knee arthroplasty treated with the Oxford Phase III (Zimmer Biomet, Warsaw, Indiana) mobile-bearing UKA *versus* TKA with the Vanguard Complete Knee System (Zimmer Biomet) and found a faster return to a more functional level with UKA.[9]

The development of UKA has progressed significantly since its first inception in the 1970s.[22,23] The mobile-bearing concept, developed in Oxford, United Kingdom, and described by Goodfellow and O'Connor,[24] has been maintained throughout the years while technological advancements have been made through phases of the design. The earliest phase of the Oxford mobile-bearing UKA was implanted using cutting blocks, while the newest instrumentation employs a distal femur bone mill and allows precise bone removal to facilitate accurate balancing of flexion and extension gaps.[22,25] Subsequent design phases resulted in minimally invasive techniques, and improved rehabilitation and functional outcomes.[26] Recently, the Oxford Phase III femoral component (Zimmer Biomet) was redesigned.

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Table I. Pre-operative demographics

Characteristic	UKA group	TKA group	p-value
Patients (n)	168	177	
Knees(n)	201	189	
Gender of patients (n, %)			0.136
Male	72 *(43)*	62 *(35)*	
Female	96 *(57)*	115 *(65)*	
Age (yrs)	63.3 (SD 9.0, 38 to 84)	65.7 (SD 8.2, 45 to 86)	0.008
Height (inches)	66.8 (SD 4.2, 59 to 77)	66.2 (SD 4.0, 58 to 79)	0.127
Weight (pounds)	205 (SD 43, 128 to 350)	215 (SD 59, 104 to 390)	0.065
Body mass index (kg/m^2)	32.2 (SD 5.9, 21 to 53)	34.5 (SD 9.1, 17 to 63)	0.004
Pre-operative range of movement (°)	115.1° (SD 11.2°, 20° to 130°)	106.7° (SD 14.0°, 60° to 130°)	< 0.001
Pre-operative Knee Society pain score (0 to 50 possible)	8.6 (SD 10.1, 0 to 50)	8.2 (SD 10.9, 0 to 50)	0.692
Pre-operative Knee Society clinical score (0 to 100 possible)	39.7 (SD 13.5, 18 to 100)	39.6 (SD 15.0, 8 to 84)	0.919
Pre-operative Knee Society function score (0 to 100 possible)	57.9 (SD 18.0, 0 to 100)	50.6 (SD 18.1, 0 to 100)	< 0.001

UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty; SD, standard deviation

The current Oxford Partial Knee Twin-Peg incorporates an additional femoral peg for improved stability and an additional 15° of femoral articular surface for greater contact in deep flexion. The twin-peg design also includes a more rounded profile for enhanced fit into the milled surface.

Since the redesign of the Oxford Phase III mobile-bearing UKA to a twin-peg femoral implant, there has not been a direct comparison with TKA. We sought to revisit our previous comparison of UKA *versus* TKA,[9] this time comparing patients treated with the new UKA design to those treated with the same TKA system as before. We evaluated the revision rates, frequency of complications, requirements for manipulation and post-operative function.

Patients and Methods

A search of our practice registry revealed 184 patients (219 knees) who had signed a general research consent allowing retrospective review, who underwent medial UKA performed by one of two surgeons (AVL, KRB) with the Oxford Partial Knee Twin-Peg device between February and October 2009. Indications for medial mobile-bearing UKA are full thickness medial cartilage loss, anterior disease with preserved posterior bone, fully correctable varus deformity and intact full thickness lateral compartment articular cartilage, and an intact anterior cruciate ligament, while disregarding traditional limitations of age, weight, patellofemoral disease and anterior knee pain. Exclusion criteria included tricompartmental osteoarthritis confirmed by radiograph, arthroscopy or intra-operatively, failure of lateral stress radiographs, active infection and patients who had responded to initial conservative therapy. These patients were compared with a randomly selected group of 212 consented patients (228 knees) treated with primary TKA using the Vanguard Complete Knee System (Zimmer Biomet) by the same two surgeons between February and March 2009. Underlying diagnoses for TKA were osteoarthritis in 217 knees (95%), rheumatoid arthritis in eight, and post-traumatic arthritis in three. In the UKA group, five patients (five knees) died prior to returning for minimum two-year follow-up, and 11 presumed living patients (13 knees) who have not returned for minimum two-year follow-up and have been lost to contact, leaving a cohort of 168 patients (201 knees) available for review with minimum two-year follow-up. There were no patient deaths within 90 days of UKA. In the TKA group, 19 patients (20 knees) died prior to returning for minimum two-year follow-up, and 16 presumed living patients (19 knees) who have not returned for minimum two-year follow-up who have been lost to contact, leaving 177 patients (189 knees) available for review with minimum two-year follow-up. One patient, who was progressing satisfactorily at her six-week post-operative visit, died 73 days post-operatively, unrelated to her TKA. The characteristics of both groups of patients are presented in Table I.

A midline approach with medial parapatellar arthrotomy was used for both procedures. UKA was performed without extension to the vastus medialis obliquus and without patellar eversion. Subsequent to the current study, instrumentation incorporating intramedullary femoral alignment guide and an anti-impingement guide were developed to facilitate implantation of the new femoral component. However, instrumentation used for UKA in the current study was the earlier Phase III instrumentation. All components were cemented in both groups. All patellae were resurfaced in the TKA group. The Vanguard TKA femoral components were cruciate-retaining (CR) in 186 knees (98%) and posterior-stabilised in three knees. All patients underwent the same multimodal rapid recovery pre-operative and post-operative protocols as previously described.[27,28] Patients were seen initially at six weeks post-operatively and annually thereafter. Patient demographics, including height, weight, body mass index (BMI), and age were collected from the pre-operative records. Knee Society clinical score (KSC), pain score (KSP) and function score (KSF) were recorded. ROM was measured with an electric goniometer. Revision, re-operation and manipulation

Table II. Post-operative results

Characteristic	UKA group	TKA group	p-value
Follow-up (yrs)	5.4 (SD 0.8, 2 to 7)	5.5 (SD 1.2, 2 to 7)	0.503
Length of hospital stay (days)	1.4 (SD 0.7, 1 to 4)	2.1 (SD 1.0, 1 to 7)	< 0.001
Discharge disposition			< 0.001
Not available	7 *(4)*	0 *(0)*	
Home	183 *(91)*	150 *(79)*	
Extended care facility	11 *(6)*	39 *(21)*	
Post-operative range of movement (°)	118.7° (SD 9.2°, 85° to 140°)	111.6° (SD 12.4°, 70° to 140°)	< 0.001
Improvement in range of movement from pre-operative to most recent (°)	3.7° (SD 11.9°, -20° to 95°)	4.9° (SD 14.5°, -40° to 55°)	0.382
Post-operative Knee Society pain score (0 to 50 possible)	44.0 (SD 13.0, 0 to 50)	45.6 (SD 10.7, 0 to 50)	0.195
Improvement in Knee Society pain score from pre-operative to most recent	35.4 (SD 17.3, -20 to 50)	37.3 (SD 14.6, -20 to 50)	0.225
Post-operative Knee Society clinical score (0 to 100 possible)	90.3 (SD 15.5, 31 to 100)	88.6 (SD 14.2, 45 to 100)	0.265
Improvement in Knee Society clinical score from pre-operative to most recent	50.8 (SD 20.7, -35 to 81)	49.1 (SD 20.8, -11 to 81)	0.420
Post-operative Knee Society function score (0 to 100 possible)	77.6 (SD 24.3, 0 to 100)	66.0 (SD 27.8, 0 to 100)	< 0.001
Improvement in Knee Society function score from pre-operative to most recent	19.3 (SD 25.8, -55 to 100)	15.3 (SD 25.8, -55 to 90)	0.135

UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty; UKA, SD, standard deviation

under anesthesia rates were all recorded. Post-operative radiographs were evaluated for signs of hardware loosening, osteolysis, and component positioning and alignment.

Statistical analysis. We compared differences in the continuous variables (age, follow-up duration, BMI, ROM, length of stay and clinical scores) between groups using mean values, ranges and standard deviations (SD) with non-paired, two-tailed Student *t*-tests. We compared differences in discharge disposition, revision, re-operation, manipulation requirement, and complication rates between the two groups using chi-squared analysis. We calculated 95% confidence intervals (CI) and significance was determined as a p-value < 0.05.

Results

The mean follow-up in the TKA group was 5.5 years and 5.4 years for the UKA group (2 to 7). Pre-operatively, patients in the UKA group were somewhat younger (mean 63.3 years *vs* 65.7 years, p = 0.008), had a lower mean BMI (32.2 kg/m^2 *vs* 34.5 kg/m^2, p = 0.004), higher pre-operative mean KS functional scores (57.9 *vs* 50.6, p < 0.001), and greater mean ROM (115° *vs* 107°, p < 0.001). Pre-operative mean KS clinical and pain scores were similar (Table I).

Post-operatively, the twin-peg UKA cohort demonstrated higher mean KS functional scores (78 *vs* 66, p < 0.001) and ROM (119° *vs* 112°, p < 0. 001) (Table II). When considering functional improvement from pre-operative levels to most recent evaluation, mean KS functional scores demonstrated a trend toward greater improvement in the UKA group compared with the TKA group that did not reach statistical significance (19.3 *vs* 15.3, p = 0.135). Mean improvement in the ROM from pre-operative levels was similar between the groups (3.7° for UKA *vs* 4.9° for TKA, p = 0.382). Mean post-operative Knee Society pain and clinical scores were similar between groups, as were improvements from pre-operative levels for these outcome measures.

Post-operative radiographs were available to review for signs of hardware loosening, osteolysis, and component alignment in 386 knees. In the TKA group, patella infera was noted in one patient. In the UKA group, an "anvil" osteophyte (osteophyte seen along the base of the anterior cruciate ligament) was noted in one patient after falling from a bicycle and fracturing his ipsilateral hip, an asymptomatic radiolucency medial to the tibial keel was noted in one patient, and asymptomatic osteoarthritic changes to the patellofemoral joint were noted in another patient. Satisfactory fixation, position and alignment were observed for the remainder of patients with no evidence of osteolysis.

Overall nine component revisions were performed in our study: three in the UKA group (3 of 201, 1.5%) compared with six in the TKA group (6 of 189, 3.2%, p = 0.269) (Table III). Reasons for UKA failure were arthritic progression in two knees and tibial collapse in one. In all three patients the UKA was revised to a Vanguard CR TKA, one with a standard CR bearing and two with anterior stabilised bearings. TKA failure modes were two full component exchanges to constrained condylar devices for two-stage treatment of infection, one full revision to a rotating hinge at six years for periprosthetic fracture, and three bearing only exchanges with one each for arthrofibrosis, instability and polyethylene wear. Manipulation for arthrofibrosis was required after 16 TKA (16 of 189, 8.5%) *versus* no UKA (p < 0.001). In the UKA group, in addition to the three knees revised there were four complications requiring re-operation: three arthroscopic debridements, with two for removal of a loose body and in one of these, lateral meniscectomy, and one for osteophyte removal and lysis of adhesions; and one open incision and debridement of a non-healing wound. In the TKA group, in addition to the three full component revisions and three bearing only revisions, there were three complications requiring further surgery: two incision and debridement procedures with one for superficial infection after a dental abscess and one for

Table III. Complications and revisions

Characteristic (n, %)	UKA group	TKA group	p-value
Manipulation	0 *(0.0)*	16 *(8.5)*	< 0.001
Any re-operation	7 *(3.5)*	9 *(4.8)*	0.524
Revision of any component	3 *(1.5)*	6 *(3.2)*	0.269

UKA, unicompartmental knee arthroplasty; TKA, total knee arthroplasty

wound dehiscence, and one excision of a prepatellar suture granuloma.

Discussion

In the current study, while the revision rate after primary TKA was twice that of medial mobile-bearing UKA at minimum two-year and mean 5.5- and 5.4-year follow-up, the difference was not significant with numbers available. Revision in all three failed UKAs was accomplished with a primary-type CR TKA, whereas the three full revisions in the TKA group required constrained condylar or rotating hinge devices. Survival with the Oxford Twin-Peg Partial Knee was 98.5% with an endpoint of implant revision. In a previous study from our centre of patients who underwent 1000 consecutive medial Oxford Phase III UKAs with minimum two-year follow-up (mean 3.7 years) reported survivorship was 95.2% with an endpoint of implant revision.[29] Good success and long-term survival for patients treated with mobile-bearing UKA has been demonstrated by other centres as well. Pandit et al[30] prospectively reported on their first 1000 Oxford Phase III UKAs with a 2.9% re-operation rate and 96% ten-year survival rate. Their experience at 15 years yielded 91% survivorship with an endpoint of all re-operations or 99% survivorship for an endpoint of revision for implant failure.[31] Price and Svärd[32] reported first and second decade survivorship of mobile-bearing UKA at 94% and 91%, respectively. White, Roberts and Kuiper[33] recently reported results of 248 patients (287 knees) implanted with the cemented Oxford Twin-Peg Partial Knee reviewed at a mean follow-up of 5.1 years (maximum 9.2), and observed 98% cumulative implant survival. They stated that survivorship of the twin-peg UKA was superior to that of the single-peg knee at their centre, although another study found little difference between the two.[34]

In contrast, other authors have demonstrated diminished results in direct comparison to TKA. Lyons et al[35] reported a 6.4% TKA revision rate *versus* 12.9% UKA revision rate at mean follow-ups of 6.5 and 7.1 years respectively. Niinimaki et al[20] evaluated the Finnish Arthroplasty Registry and reported 90.4% survivorship at five years for mobile-bearing UKA compared with 96.3% survivorship at five years for all TKA. Although these studies demonstrated inferior results to UKAs, both study periods included implants from 1978 and 1985, respectively. Newer technological designs may influence revision rates and survivorship analysis.

Many papers have ubiquitously shown patients receiving UKA have higher pre-operative and post-operative clinical function scores and ROM.[5,9,13,35-38] Critics comment that these papers do not demonstrate significance when looking for the change between pre- and post-operative outcomes. More recent studies have looked at this change. Walker et al[39] reported substantially better post-operative Oxford knee scores[40] (increase in 14.3 *vs* 9.6) and ROM (127 *vs* 107) in 22 matched pair knees for patients treated with UKA *versus* TKA for isolated lateral osteoarthritis at mean follow-ups of 22 and 19 months, respectively. They also found UKA patients to have more improved scores and ROM compared with TKA patients. Our analysis likewise demonstrated greater improvement in the Knee Society functional scores for medial UKA patients *versus* TKA patients that was significant at earlier follow-up intervals, but was less pronounced when only considering patients with minimum two-year follow-up.

In our study, manipulation rates in the TKA cohort were higher than the UKA cohort. Arthrofibrosis after TKA resulting in manipulation can range from 1% to 9%.[41] However, manipulation after UKA is exceedingly rare.[42] In addition, anaesthesia required for manipulation may carry risk. Although dependent on many factors, including American Society of Anesthesiologists (ASA) score,[43] comorbidities such as diabetes, heart disease and pulmonary disease, administration of general anaesthesia has an all-cause mortality risk associated with it. Bainbridge et al[44] reports all-cause mortality depending on ASA 1 to 3 as 0.48% and ASA 4 to 5 as 9.32%.

As technology improves, we have seen the indications for UKA expand. Relative contraindications, such as BMI greater than 32 kg/m^2, age younger than 60 years, weight greater than 82 kg, mild patellofemoral disease, and anterior knee pain have not yielded diminished results in recent studies.[45-48]

Although our follow-up results are early, our initial revision rates are comparable between UKA and TKA groups using the Oxford twin-peg medial mobile-bearing UKA. Other strengths of this paper include evaluation of the difference in changes between clinical outcome scores, single institution, same technique, and same implants.

There were some limitations to our study. First, it was retrospective and may be subject to selection bias. Pre-operative findings revealed that patients in the UKA group had higher functional scores, lower BMI, and lower age indicating a selection bias toward opting for the UKA

procedure in healthier, more active patients.[49] Although a selection bias is commonly seen in comparison studies between UKA and TKA, analysis of the improvement between pre-operative and post-operative levels indicated benefits for the choice of UKA over TKA. Greater BMI may no longer be a risk factor for adverse events and increased failure in UKA surgery, as demonstrated by recent studies.[45,46,48] Some authors may argue younger, lower BMI patients are typically more active, resulting in higher functional scores, better outcomes and lower manipulations regardless of surgery. Although this may be true, our study looked at the specific change in functional score before and after surgery, which may mitigate that benefit. Howell et al[49] demonstrated that patients selected and planned for UKA but converted intra-operatively to TKA have outcomes similar to patients who received UKA and better results than patients originally planned and selected to receive TKA. An additional confounding factor is the inclusion of eight rheumatoid arthritic and three post-traumatic arthritis patients in the TKA cohort which may skew our results. Another limitation resulting from the retrospective nature is that 30 patients (31 knees) died during the study period, and 24 of those patients (24 knees) had not been seen for a two-year clinical follow-up visit. Only seven of the patients died before reaching two years post-operatively. We know that one patient had a revision before death. The other patients had no known complications or revisions at the time of last follow-up. Another weakness of the study is that in addition to the 24 patients who died before a two-year clinical assessment, minimum follow-up was not available for 32 knees in 27 presumed living patients. The Social Security Death Index and online obituaries were searched for all patients. Attempts were made to contact the patients at their last known address and telephone numbers, by contacting referring and family physicians listed, and by searching available free internet services. However, minimum two-year clinical follow-up was available for 87% of patients.

In conclusion, our study showed fewer manipulations, and higher functional outcomes for patients treated with medial mobile-bearing UKA compared with TKA. TKA had twice the revision rate as UKA although this did not reach significance with numbers available. Newer technology may improve the functional outcomes and durability of medial mobile-bearing UKA, with implant survival that may be comparable with TKA. Further study with longer follow-up will determine if medial mobile-bearing UKA with enhanced twin-peg design will continue to demonstrate equivalent or better long-term survivorship and functional outcome.

Take home message:

We have seen fewer manipulations and higher functional outcomes with the Oxford Partial Knee Twin-Peg mobile bearing unicompartmental knee arthroplasty compared with total knee arthroplasty in the short-term.

Author contributions:
Z. C. Lum: Writing the paper.
A. V. Lombardi: Performed surgery.
J. M. Hurst: Performed surgery.
M. J. Morris: Performed surgery.
J. B. Adams: Data analysis.
K. R. Berend: Performed surgery.

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■ KNEE

The results of Oxford unicompartmental knee arthroplasty in the United States

A MEAN TEN-YEAR SURVIVAL ANALYSIS

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Aims

Approved by the Food and Drug Administration in 2004, the Phase III Oxford Medial Partial Knee is used to treat anteromedial osteoarthritis (AMOA) in patients with an intact anterior cruciate ligament. This unicompartmental knee arthroplasty (UKA) is relatively new in the United States, and therefore long-term American results are lacking.

Patients and Methods

This is a single surgeon, retrospective study based on prospectively collected data, analysing a consecutive series of primary UKAs using the Phase III mobile-bearing Oxford Knee and Phase III instrumentation.

Between July 2004 and December 2006, the senior author (RHE) carried out a medial UKA in 173 patients (213 knees) for anteromedial osteoarthritis or avascular necrosis (AVN).

A total of 95 patients were men and 78 were women. Their mean age at surgery was 67 years (38 to 89) and mean body mass index 29.87 kg/m2 (17 to 62).

The mean follow-up was ten years (4 to 11).

Results

Survivorship of the Oxford UKA at ten years was 88%, using life table analysis. Implant survivorship at ten years was 95%. The most common cause for revision was the progression of osteoarthritis in the lateral compartment. The mean knee score element of the American Knee Society Score (AKSS) was 50 pre-operatively and increased to 93 post-operatively. The mean AKSS function score was 56 pre-operatively rising to 78 post-operatively

Conclusion

This ten-year follow-up study of the Oxford UKA undertaken in the United States shows good survivorship and excellent function in a wide selection of patients with AMOA and AVN.

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The Oxford unicompartmental knee arthroplasty (UKA) is primarily indicated for patients with anteromedial osteoarthritis (AMOA) of the knee.[1] AMOA with a functionally intact anterior cruciate ligament (ACL), is a clinicopathological entity characterised by a specific wear pattern of cartilage and bone erosion limited to the anterior and centromedial compartment of the knee. Knees with AMOA tend to be in varus alignment and are not painful in flexion because the posterior elements of the joint are preserved, consequently protecting the medial collateral ligament (MCL) from shortening.[1]

This study is a longitudinal follow-up of a consecutive series of medial UKAs. It aims to determine the survivorship of the implant and patient-reported outcomes. It also proposes criteria for the appropriate selection of patients for UKA and provides an in-depth analysis of revision cases. It is the first ten-year follow-up of a mobile-bearing medial UKA undertaken in the United States since the Food and Drug Administration (FDA) approved the device in 2004.

Patients and Methods

This is a retrospective review of prospectively collected data in a practice-based registry. Patients were followed-up at six weeks, six months, one year, and every two years after the first post-operative year.

Between July 2004 and December 2006, the senior author (RHE) carried out 213 consecutive primary medial UKAs in 173 patients using the Phase III mobile-bearing cemented

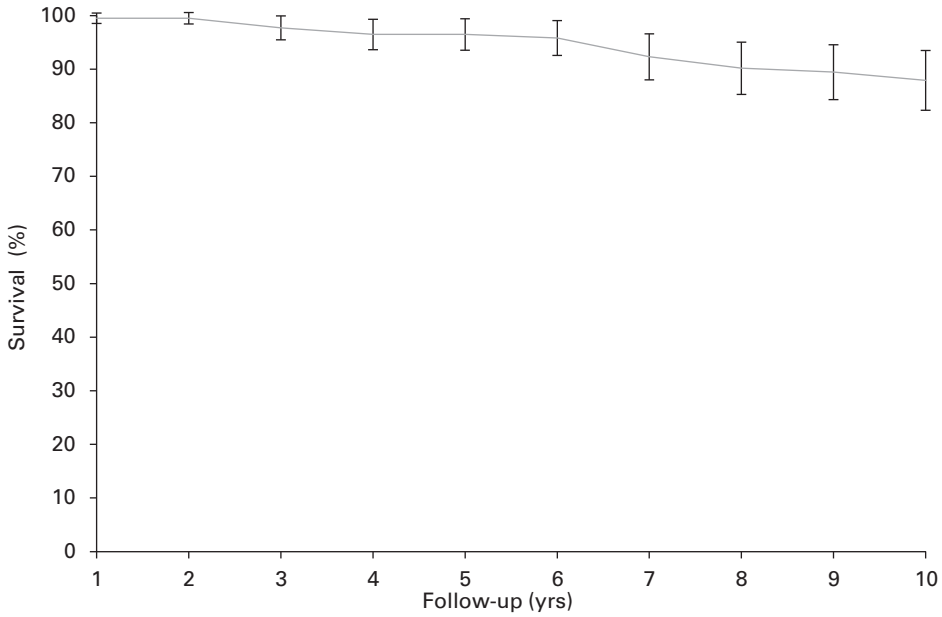

Fig. 1

Unicompartmental knee arthroplasty (UKA) survivorship at ten years - survival curve showing survival of the minimally invasive Oxford phase III UKA with all revisions as the end point.

Oxford Knee (Zimmer Biomet, Warsaw, Indiana), Phase III instrumentation and a minimally invasive surgical approach. There were 95 men and 78 women in the series. Their mean age at surgery was 67 years (38 to 89) and mean body mass index (BMI) 30 kg/m^2 (17 to 62).

Follow-up consisted of establishing the American Knee Society Score (AKSS) and obtaining anteroposterior and lateral radiographs. Range of movement (ROM) was assessed with the patient supine, measuring from the lateral side by placing a 12-inch goniometer in a line from the greater trochanter to the lateral femoral condyle and thence to lateral malleolus.[2]

The AKSS is a validated total knee rating system. It is subdivided into a knee score which rates the knee joint, and a functional score which rates the patient's ability to walk and climb stairs (both scores have a maximum of 100 points).[3] The pre-operative score closest to surgery and the most recent post-operative score were used in each case in this study. Patients who had not completed a recent follow-up visit were contacted by phone and were asked AKSS questions related to pain, function, and status of the implant. In order to determine the status of deceased patients' implants, their most recent hospital and clinical records were obtained. Evidence of the implant label, to ensure that an Oxford UKA had been implanted, as well as patient confirmation of implant status, were required to establish survivorship.

The primary indications for Oxford UKA are patients with AMOA; bone-on-bone medially; intact anterior cruciate and collateral ligaments; a correctable varus deformity; asymptomatic or absent patellofemoral disease and full cartilage thickness laterally. Secondary indications are osteonecrosis or avascular necrosis (AVN) limited to the medial compartment. Contraindications previously described by Kozinn and Scott[4] (age, BMI, activity level, chondrocalcinosis, etc.) were not considered to be contraindications. Absolute contraindications are lateral compartment disease; symptomatic patellofemoral disease; ligament instability, excessive flexion contracture, and the presence of any infection or inflammatory disease. Patellofemoral arthritis limited to the medial side was not considered a contraindication, although if present on the lateral side, was deemed to be so. The final decision to carry out a UKA was made intra-operatively after verifying the integrity of the ACL and the lateral tibiofemoral compartment.

Statistical analysis. A survival analysis was undertaken using the life table method for various definitions of failure.[5]

UKA survivorship considered all revisions as the end point, regardless of cause. Revisions were defined as any replacement of components. Implant survivorship did not include revisions at which the original Oxford implant was determined to be well fixed and functional (confirmed from the operating record), but was nonetheless revised either because of lateral compartmental osteoarthritis (LCOA) or haemarthrosis. The 95% confidence intervals (CI) were calculated using the Peto method.[6] Statistical analysis and graphs were prepared using Microsoft Excel (Microsoft, Redmond, Washington) macros.

Results

The mean follow-up was ten years (4 to 11). Patient contact was attempted by phone and mail. Of the 173 patients

Table I. Life table for all 213 unicompartmental knee arthroplasties with implant-related revisions as the endpoint. Lost to follow-up (LTF), revision rate (Rev rate), success rate (Suc rate), survivorship percentage (% Surv)

Yrs	n	Revised	Deaths	LTF	n (at risk)	Rev rate	Suc rate	% Surv	95% CI
1	213	1	0	30	198	0.01	0.99	99.5	1.0
2	182	0	1	12	175.5	0.00	1.00	99.5	1.0
3	169	3	0	4	167	0.02	0.98	97.7	2.2
4	162	2	0	8	158	0.01	0.99	96.5	2.8
5	152	0	0	9	147.5	0.00	1.00	96.5	2.9
6	143	1	2	2	141	0.01	0.99	95.8	3.2
7	138	5	0	2	137	0.04	0.96	92.3	4.3
8	131	3	1	1	130	0.02	0.98	90.2	4.9
9	126	1	0	4	124	0.01	0.99	89.4	5.1
10	121	2	5	6	115.5	0.02	0.98	87.9	5.6

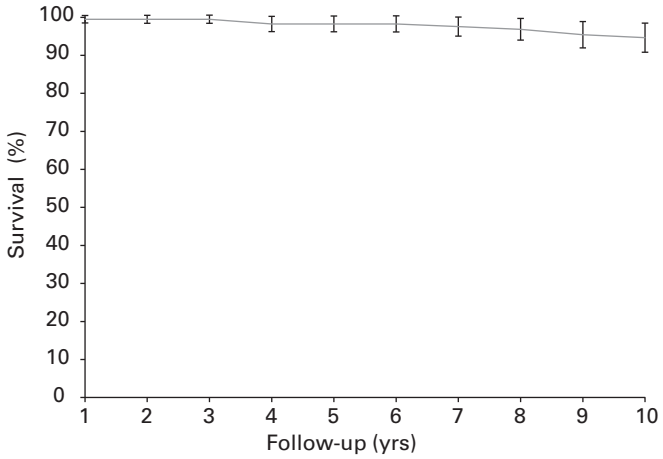

Fig. 2

Implant survivorship at 10 years - survival curve showing survival of the minimally Oxford phase III unicompartmental knee arthroplasty with non-implant related revisions as the endpoint.

(213 knees), nine patients (11 knees 5%) died and 21 patients (34 knees 16%) were lost to follow-up. None of the deaths were related to the implant or surgical complications. The survivorship of the UKA at ten years was 88% (95% CI 5.6) (Fig. 1, Table I) and implant survivorship (95% CI 3.8) (Fig. 2, Table II).

Patients exhibited a good ROM post-operatively, with a mean 0.42° of extension (-10° to 10°) and 123° of flexion (90° to 140°). A total of 159 patients had an excellent post-operative AKSS knee score with six good, five fair and five poor results. The mean pre-operative AKSS knee score was 50 and rose to 93 post-operatively (0 to 95 and 0 to 100, respectively). The mean pre-operative AKSS function score was 56 and rose to 78 post-operatively (0 to 100 and -10 to 100, respectively) (Fig. 3). The mean AKSS follow-up for scores is eight years (0.5 to 11). A total of five patients (six knees) were followed-up until their recent death, and reported a mean Knee Score of 98, and a mean Knee Function Score of 88 (93 to 100 and 45 to 100, respectively).

Revisions. A total of 20 patients (20 knees; 9.4%) were revised in this study at a mean of 6.2 years (2 to 11) after Oxford UKA (Table III). The mean BMI of patients revised was 29 kg/m^2 (19 to 49), which is slightly lower than the overall mean patient BMI. Most revisions, 4.2% of all implanted Oxfords, were due to the progression of LCOA. One patient with LCOA ten years post Oxford UKA, had a well-fixed medial Oxford UKA, and was treated with the addition of a lateral UKA, and reported good outcomes through the first post-operative year (Knee Function Score 80, Knee Score 90).

All patients who underwent revision were converted to a primary total knee arthroplasty (TKA), except for three patients treated elsewhere in whom stemmed revision components were used, and one whose posteriorly dislocated bearing was revised to a thicker bearing.

We found more revisions in patients with larger bearings (Fig. 4). One was attributed to impingement-related polyethylene wear. All bearing-related revisions, for dislocation

Table II. Life table for all 213 unicompartmental knee arthroplasties with non-implant-related revisions as the endpoint. Lost to follow-up (LTF), revision rate (Rev rate), success rate (Suc rate), survivorship percentage (% Surv)

Yrs	n	Revised	Deaths	LTF	n (at risk)	Rev rate	Suc rate	% Surv	95% CI
1	213	1	0	30	198	0.01	0.99	99.5	1.0
2	182	0	1	12	175.5	0.00	1.00	99.5	1.0
3	169	0	0	4	167	0.00	1.00	99.5	1.1
4	165	2	0	8	161	0.01	0.99	98.3	2.0
5	155	0	0	9	150.5	0.00	1.00	98.3	2.1
6	146	0	2	2	144	0.00	1.00	98.3	2.1
7	142	1	0	2	141	0.01	0.99	97.6	2.5
8	139	1	1	1	138	0.01	0.99	96.9	2.9
9	136	2	0	4	134	0.01	0.99	95.4	3.5
10	130	1	5	6	124.5	0.01	0.99	94.6	3.8

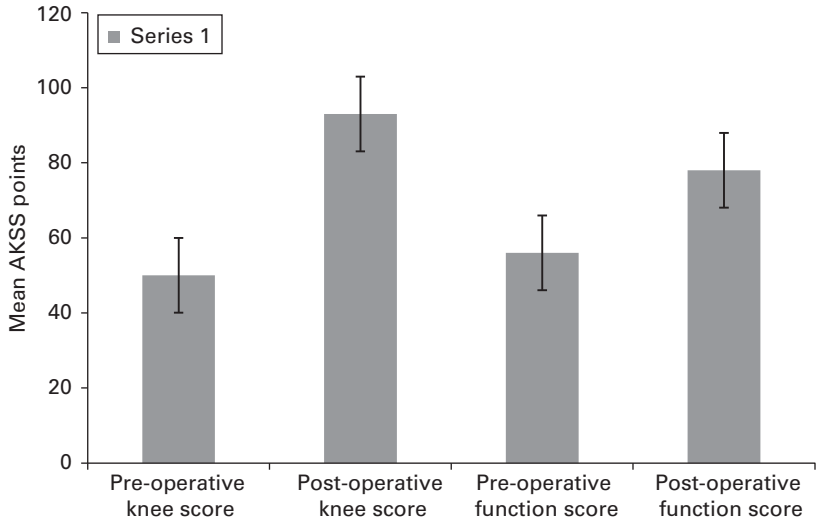

Fig. 3

American Knee Society Score (AKSS) pre- and post-operative scores - clinical outcomes (mean,SD error bars). AKSS Knee and function scores displayed. The mean AKSS follow-up for scores is 8 years (0.5 to 11).

or wear, had bearings of 5 mm or thicker. Of the nine bearings in which lateral compartment disease had progressed, three were 3 mm and six were 5 mm or more in thickness.

Component loosening (four cases; two from the tibia and two from the femur) occurred in 1.9% of the knees in our study. Haemarthrosis-related revisions occurred in three patients (1.4%). Their intra-operative findings showed the tibial and femoral components were well fixed, but there was evidence of hypertrophic synovitis and extensive cartilage staining with haemosiderin and cartilage degeneration. These patients were initially treated conservatively. Several aspirations were undertaken to alleviate pain, none of which contained any signs of infection. There was no evidence of impingement.

Discussion

The clinical outcomes in this study were comparable with those from other Oxford UKA series. Price et al,[7] Pandit et al,[8] Kort et al,[9] Rajasekhar, Das and Smith,[10] and Kim et al[11] all reported a similar improvement in clinical scores. The improvements in ROM in this study (123.4° of maximum flexion) were comparable with those in other studies (Heller et al:[12] 123°, Kort et al:[9] 126.1°, Price et al:[7] 116°, Kristensen, Holm and Varnum:[13] 127.5°).

BMI did not seem to affect survivorship. This study provides further evidence that obesity is not a contraindication to Oxford UKA.[14]

The most common cause of revision in this study was LCOA. This is consistent with other reports.[9,13,15,16] It highlights the importance of selecting patients with a normal lateral compartment at the time of primary surgery. Often, when lateral compartment osteoarthritis supervenes, the medial implant is well-fixed and well-functioning. 'Addition of a lateral UKA' (AOLU) is one method of addressing this. Pandit et al[7] states that 13.8% of all revisions out of a series of 1000 Phase III Oxford UKA were treated with an AOLU, which gave good results beyond two years. In a study of lateral UKA to treat progressive arthritis after medial UKA, Pandit et al[7] reported 100% survivorship in 27 knees after five years using this approach.[17] Treating the progression of LCOA after Oxford UKA, with AOLU rather than TKA has several

Table III. Details of the 20 revisions

Patient	Time to revision (yrs)	Reason for revision	Operative findings	Revision and outcome
1	0.73	Loose tibial component	Micromotion seen in the tibial aspect of the tibia, loose tibial component.	Revised to TKA, Vanguard CR*
2	2.1	Chronic haemarthrosis	Fresh blood discovered in the knee, full thickness cartilage loss on the trochlea and lateral compartment.	Revised to TKA, Vanguard CR
3	2.6	Chronic haemarthrosis	Progressive cartilage loss in lateral compartment, 200ml of fresh blood in joint, boggy synovium, Oxford in good position and bearing was tracking.	Revised to TKA, Vanguard CR*
4	2.7	Progression of osteoarthritis in the lateral compartment	Lupus arthritis progression into lateral compartment, original oxford components were well fixed and aligned.	Revised to TKA, Vanguard CR*
5	3	Unknown, revised elsewhere	Unknown	Revised to TKA
6	3.7	Progression of osteoarthritis in the lateral compartment	Significant arthritic erosive changes to lateral femoral condyle, previous components in please with no loosening.	Revised to TKA, Zimmer*
7	3.7	Progression of osteoarthritis in the lateral compartment	Progression of osteoarthritis in the lateral compartment	Revised to TKA, done elsewhere
8	5.9	Progression of osteoarthritis in the lateral compartment	Bone on bone lateral degenerative joint disease, Oxford components were well fixed and functioning well.	Revised to TKA, Vanguard CR*
9	6	Bearing dislocation	Posterior displacement of bearing.	Bearing change to thicker bearing.
10	6.1	Progression of osteoarthritis in the lateral compartment	Inflammatory synovitis with cartilage disease progress.	Revised to TKA, Vanguard CR
11	6.3	Progression of osteoarthritis in the lateral compartment	Progression of osteoarthritis in the lateral compartment	Revised to TKA, done elsewhere
12	6.5	Progression of osteoarthritis in the lateral compartment	Bone on bone lateral degenerative joint disease, Oxford components were well fixed and functioning well.	Revised to TKA, Vanguard PS*
13	6.9	Progression of osteoarthritis in the lateral compartment	Bone on bone lateral degenerative joint disease, Oxford components were well fixed and functioning well.	Revised to TKA, Vanguard CR*
14	7.1	Chronic haemarthrosis	Progressive cartilage loss in lateral compartment, 200 ml of fresh blood in joint, Oxford in good position and bearing was tracking.	Revised to TKA, Vanguard CR*
15	7.7	Unknown, revised elsewhere	Unknown	Revised to TKA, done elsewhere
16	8.1	Loose tibial component	Loose tibial component, lateral compartment showed no signs of wear.	Revised to TKA, Vanguard PS
17	9.5	Loose femoral component	Femoral component loose	Revised to TKA, DJO Stemmed† femur and tibia revision system (RDR)
18	9.8	Polyethylene Wear	Catastrophic failure of the bearing.	Revised to TKA, DJO Stemmed† femur and tibia revision system (RDR)
19	11	Progression of osteoarthritis in the lateral compartment	Bone on bone lateral degenerative joint disease, Oxford components were well fixed and functioning well.	Revised to TKA, Vanguard CR*
20	11	Loose femoral component	Femoral component loose	Revised to TKA, DJO Stemmed† femur and tibia revision system (RDR)

* Zimmer Biomet, Warsaw, Indiana
† DJO Global, Vista, California
TKA, total knee arthroplasty

benefits, which include a quicker recovery, minimal soft-tissue or bony damage, and a shorter hospital stay. Historically, the first partial knee implants (1976 to 1982) were actually used bi-compartmentally as a total joint replacement, with two sets of components inserted, one medially and one laterally (Phase I Oxford).[18]

Svärd et al[19] found no difference in survival between UKA and different thicknesses of bearing. However, others have correlated thicker bearings with a poorer clinical outcome. Lombardi et al[20] found that their results were substantially better with a 3 mm or 4 mm bearing (94% 15-year survival) compared with one of 5 mm or more (75% 15-year survival). Dervin et al[21] found that overstuffing the medial compartment with a bearing that was too large resulted in overcorrection of the varus deformity and stressed the lateral compartment, inducing the progression of osteoarthritis. Pandit et al[22] also found that an increased thickness of bearing was associated with significantly poorer results, and correlated a thicker bearing with a deeper tibial cut or an injury to the MCL. The Phase III

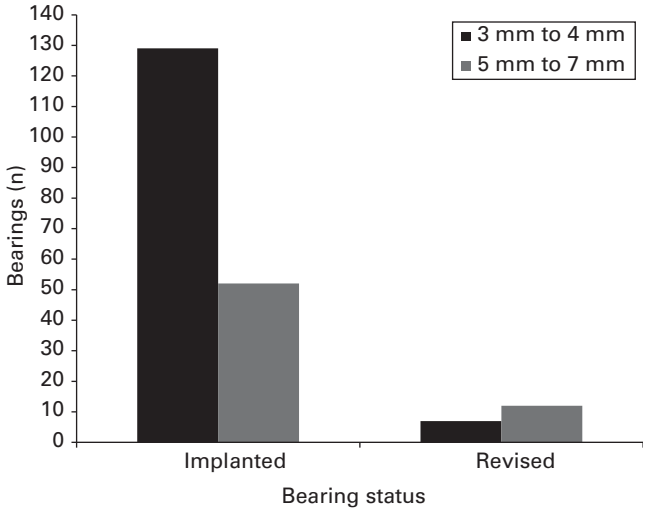

Fig. 4

Bearing thickness implanted *versus* revised: bar chart demonstrating total number of bearings implanted and revised, for thin (3 mm to 4 mm) and thick (5 mm to 7 mm) bearings.

instrumentation used in this series allowed for different amounts of tibial bone to be resected based on the surgeon's preference, resulting in possible excessive removal of tibial bone. The current microplasty instrumentation provides for more reproducible and more conservative tibial cuts[23] to accommodate the thinnest size 3 mm or 4 mm bearing.[24]

Recurrent haemarthrosis, considered to be recurrent after two consecutive episodes, was also reported as an indication for revision of an Oxford UKA by Zermatten et al,[25] but appears to be a rare complication of knee arthroplasty and is mostly reported as individual cases.[24,26-29] Recurrent haemarthrosis is more dangerous after a partial knee arthroplasty than after a TKA as normal articular cartilage has been retained. This can be damaged by bleeding, much as in the case of haemophiliac arthrosis. Data generated from pathophysiological research of osteoarthritis and rheumatoid arthritis suggests that multiple constituents in the blood trigger the process, and several joint components (articular cartilage, synovial membrane, blood vessels, and bone cells) are the targets.[30] Structural joint damage can occur after just a few haemarthroses.[30] There are a number of ways to treat this including open synovectomy,[26] radiosynovectomy,[24] interventional embolisation,[28,29] and diagnostic arthroscopy.[31]

One failure in our series was due to anterior impingement-related polyethylene wear, which highlights the importance of removing impinging bone at the time of surgery. This is confirmed by a retrieval study conducted by Kendrick et al,[32] in which it was concluded that the rate of polyethylene wear is increased if the bearings impinge on bone or cement. If there is no impingement, the rate of wear is very low (0.003 mm/year). The improved microplasty instrumentation has addressed the issue of impingement with the introduction of an anti-impingement guide. Many large series have reported no revisions for wear in the absence of impingement.[8-10,33,19,34]

According to National Joint Registers, component loosening is one of the most common causes of failure, although many clinical studies report much lower rates. Late loosening has been attributed to the accumulated effects of impact loading from impingement of the front of the bearing on the femoral condyle when the knee is in full extension.[12]

Only one of the 213 knees (0.5%) implanted underwent dislocation of the bearing: this accords with the larger Oxford studies, namely Pandit et al[8] (0.6%), Price and Svärd[16] (1%) and Yoshida et al[34] (0.8%).

The ten-year survivorship, including all revisions as an end point, was 88%. When revisions unrelated to the implant are eliminated, the ten-year survivorship was 95%, proving that the design of the implant itself is successful in retaining function and fixation in the long term. The option of retaining the medial implant and resurfacing the lateral compartment offers a less invasive, simpler solution for the knee with uncomplicated progression of osteoarthritis in the lateral compartment.

This series also shows how recurrent haemarthrosis can result in revision (three knees in this series), as such bleeding needs to be stopped before it causes a generalised arthrosis. The frequent prescribing of anti-platelet therapy may play a role in haemarthrosis of the knee.

The designer series reported a ten-year survivorship of 96%.[8] Independent centres have reported ten-year survivorship of 95%[34] and 94%.[7] The 12th annual report of the United Kingdom National Joint Registry reports the ten-year survivorship of the Oxford UKA at 88%.[35] Compared with the various studies mentioned above, our sample size was much smaller. This may explain our slightly lower survivorship on the basis of surgical caseload in determining the survival of UKAs.[36]

The strengths of this study are its prospective collection of data in a practice-based registry, and the long-term follow-up, although it is still a retrospective (longitudinal cohort) study which comes with its own limitations. A weakness of the study is the 30 patients lost to follow-up in the first year: this adversely affects the survivorship figures.

In conclusion, this is the first ten-year follow-up of the Oxford mobile-bearing medial UKA undertaken in the United States, and showed good survivorship and excellent function in a wide selection of patients with AMOA and AVN, without excluding patients on the grounds of age or BMI.

Take home message:

Medial unicompartmental knee arthroplasty with the Oxford knee have proven good long-term survivorship and functionality in patients with osteoarthritis, without excluding for age or BMI.

Author contributions:
R. H. Emerson: Senior author and senior surgeon, Performed all surgeries on patients in this study, Final edit of manuscript.
O. Alnachoukati: Primary and corresponding author, Performed statistical analysis on all data, Data capture, acquisition and compilation, Patient outreach.
J. Barrington: Second edit and contribution to introduction and discussion sections.
K. Ennin: Third edit and contribution to introduction and discussion sections.

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■ KNEE

Ten- to 15-year results of the Oxford Phase III mobile unicompartmental knee arthroplasty

A PROSPECTIVE STUDY FROM A NON-DESIGNER GROUP

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Aims

The interest in unicompartmental knee arthroplasty (UKA) for medial osteoarthritis has increased rapidly but the long-term follow-up of the Oxford UKAs has yet to be analysed in non-designer centres. We have examined our ten- to 15-year clinical and radiological follow-up data for the Oxford Phase III UKAs.

Patients and Methods

Between January 1999 and January 2005 a total of 138 consecutive Oxford Phase III arthroplasties were performed by a single surgeon in 129 patients for medial compartment osteoarthritis (71 right and 67 left knees, mean age 72.0 years (47 to 91), mean body mass index 28.2 (20.7 to 52.2)). Both clinical data and radiographs were prospectively recorded and obtained at intervals. Of the 129 patients, 32 patients (32 knees) died, ten patients (12 knees) were not able to take part in the final clinical and radiological assessment due to physical and mental conditions, but via telephone interview it was confirmed that none of these ten patients (12 knees) had a revision of the knee arthroplasty. One patient (two knees) was lost to follow-up.

Results

The mean follow-up was 11.7 years (10 to 15). A total of 11 knees (8%) were revised. The survival at 15 years with revision for any reason as the endpoint was 90.6% (95% confidence interval (CI) 85.2 to 96.0) and revision related to the prosthesis was 99.3% (95% CI 97.9 to 100). The mean total Knee Society Score was 47 (0 to 80) pre-operatively and 81 (30 to 100) at latest follow-up. The mean Oxford Knee Score was 19 (12 to 40) pre-operatively and 42 (28 to 55) at final follow-up. Radiolucency beneath the tibial component occurred in 22 of 81 prostheses (27.2%) without evidence of loosening.

Conclusion

This study supports the use of UKA in medial compartment osteoarthritis with excellent long-term functional and radiological outcomes with an excellent 15-year survival rate.

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Interest in unicompartmental knee arthroplasty (UKA) for medial osteoarthritis has increased rapidly over the last two decades.[1] The main reasons for its rising popularity are the introduction of minimally invasive surgical (MIS) techniques[2,3] with modified surgical instruments, the publication of the excellent medium- and long-term results of the Oxford Phase II arthroplasty (Zimmer Biomet Ltd, Swindon, United Kingdom)[4-7] and the well documented improved polyethylene wear characteristics of the mobile bearing device.[8] Medial osteoarthritis of the knee is considered to be a unicompartmental disease and, when left untreated, may later progress to involve the other knee compartments.[9] This has given rise to the rationale for treatment of only one compartment, either with a high tibial osteotomy (HTO) or a UKA. We describe our experience of using the Oxford Phase III (Zimmer Biomet Ltd) prosthesis, with a minimally invasive technique, implanted by a single surgeon and focuses on post-operative knee function, number and reason for revision operations, pain and radiological results. The medium-term outcome of the Oxford Phase III-UKA is reported in other studies.[10-13] We hypothesise that this study demonstrates the effectiveness and safety of a minimally invasive surgical approach for implanting the Oxford UKA with good to excellent long-term follow-up. This is the first study that reports the survival, clinical and radiological outcomes of the Oxford Phase III UKA after a minimum of ten years follow-up.

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Table I. Demographic baseline characteristics of 138 knees in 129 patients treated by means of unicompartmental knee arthroplasty for medial compartment osteoarthritis

Number of prosthesis	n = 138 (129 patients)
Side	71 right; 67 left
Age (yrs), median (range), IQR	72.0 (47 to 91), IQR 12.0
Body mass index (kg/m^2), mean SD (range), IQR	28.2 SD 4.8 (20.7 to 52.2), IQR 5.2
Operation time (mins) mean SD (range), IQR	71.5 SD 13.7 (50 to 120), IQR 10.0

IQR, interquartile range; SD, standard deviation

Materials and Methods

Between January 1999 and January 2005, 138 medial Oxford Phase III arthroplasties (129 patients) were performed in a district general hospital by a single surgeon (AEL). There were no one-stage bilateral UKAs. All patients were diagnosed with medial compartment osteoarthritis of the knee based on history, physical examination and radiographs: short-length weight-bearing anteroposterior (AP), lateral, axial patellar view and tunnel view. Stress radiographs were done on indication when clinical examination showed some medial collateral ligament stiffness. The strict indication criteria for UKA were followed.[14,15] Osteoarthritis of the patellofemoral joint and obesity were not considered contraindications for this procedure. The patients' demographic details are shown in Table I. Medium-term (mean follow-up 4.2 years, 1 to 10.4) results of this Oxford Phase III cohort were reported in 2011.[13] This report is a follow-up study of the original patient cohort with a minimal ten years' follow-up.

A total of 32 patients (32 knees) died in the study period (mean 6.7 years post-operatively, 1 to 11.5), none of them as a result of the surgery. These patients were analysed until the latest follow-up recorded. Among these patients one UKA was revised to a total knee arthroplasty (TKA) for disease progression of the lateral compartment. A total of ten patients (12 knees) did not attend the outpatient clinic for their last follow-up due to general health related reasons. These patients or their relatives were subsequently interviewed by telephone and none of them had undergone a revision operation. One patient (two knees) was considered as lost to follow-up. A total of 11 patients (11 knees) were revised to TKA. In total 75 patients (81 knees) were assessed at the outpatient clinic for a final follow-up at a minimum ten years. This study was performed as routine follow-up and examination was performed in accordance with generally accepted practice. Approval was obtained from our institutional review board.

Surgical technique. The cemented Oxford Phase III UKA consists of cobalt chromium molybdenum spherical femoral and flat tibial component on which a fully congruent polyethylene mobile bearing is seated. The MIS operation technique has been described in detail by Price et al.[16] The instruments available not only allow better component positioning compared with the Phase II implant, but also create a reproducible balance of the flexion and extension gap to achieve improved stability. Before cementing, pulsed lavage is used to rinse the subchondral bone. Full weight-bearing was allowed immediately post-operatively and thromboprophylaxis (Fraxiparine 2850 IU, GlaxoSmith-Kline, Zeist, The Netherlands) was prescribed for six weeks.

Outcome measures. The clinical follow-up consisted of a routine physical examination of the knee with range of movement (ROM) and stability testing, registration of pain and satisfaction with the visual analogue scale (VAS, 0 to 10 best to worst), complications and a standard series of radiographs: short-length weight-bearing AP, lateral and axial patellar views. Patients attended the routine follow-up assessments in the outpatient clinic scheduled at six weeks, six months, and two, five, ten and 15 years. Revision was defined as any surgical procedure that resulted in the removal or exchange of any of the arthroplasty components. Pain, function and health-related quality of life were evaluated pre- and post-operatively by patient- and assessor-based outcome scores validated in Dutch. The Western Ontario and McMaster Universities Arthritis Index (WOMAC Score),[17] Oxford Knee Score,[18,19] the Knee Society Score (KSS)[20,21] and VAS for pain and satisfaction were used.[22,23] A limiting factor in the study design was that the pre-operative pain VAS was not included from the start. We continued to only use the VAS post-operatively once it was added to the study protocol.

The accuracy of implant positioning (varus, valgus, flexion and extension of the implant) was determined by short-length weight-bearing AP and lateral knee radiographs on first outpatient assessment and then at routine outpatient clinic visits. A fluoroscopic-centred technique, in which the x-ray beam was perfectly aligned to be perpendicular to the implant interfaces as described by Gulati et al,[24] was applied by the senior author (AEL) to assess any (partial or complete) radiolucency at the bone-cement interface above the femoral component and under the tibial component. A radiolucent line < 2 mm width with a sclerotic line beneath the tibial component was considered to be physiological. Any line > 2 mm without a thin sclerotic bordering line was considered as a pathological radiolucency.[25] Partial or complete radiolucency refers to the extent of the line bordering the component.[24] The presence and extent of radiolucency were investigated in 75 available patients (81 knees).

Statistical analysis. A survival table was constructed and the cumulative rates were calculated using the Kaplan–Meier survival analysis[26] with a 95% confidence interval

Table II. Outcome results of 81 patients treated by means of unicompartmental knee arthroplasty for medial compartment osteoarthritis with minimum ten years' follow-up (mean with standard deviation (SD))

	Pre-operative	6 mths post-operative	5 yrs post-operative	Final follow-up (mean 11.7 yrs; 9 to 16)
Oxford Knee Score	19.4 (SD 6.8)	36.9 (SD 8.4)	38.8 (SD 8.3)	41.9 (SD 6.4)
VAS satisfaction (cm)	NA	0.8 (SD 0.8)	1.4 (SD 1.2)	1.5 (SD 1.3)
VAS pain (cm)	NA	1.3 (SD 1.1)	1.8 (SD 1.4)	1.8 (SD 1.4)
WOMAC pain score	45.6 (SD 17.2)	85.4 (SD 15.7)	86.4 (SD 17.0)	92.9 (SD 10.4)
WOMAC stiffness score	49.4 (SD 20.7)	72.7 (SD 20.8)	77.0 (SD 21.1)	89.5 (SD 12.5)
WOMAC function score	47.3 (SD 20.7)	81.5 (SD 20.8)	83.7 (SD 17.5)	89.4 (SD 11.9)
KSS total score	47.0 (SD 17.5)	89.7 (SD 15.3)	84.1 (SD 19.5)	81.0 (SD 20.7)
ROM (degrees)	121.9 (SD 10.7)	125.7 (SD 10.8)	129 (SD 9.6)	125.0 (SD 7.8)

NA, item not available; VAS, visual analogue score; WOMAC, Western Ontario and McMaster Universities Arthritis Index; KSS, Knee Society Score; ROM, range of movement

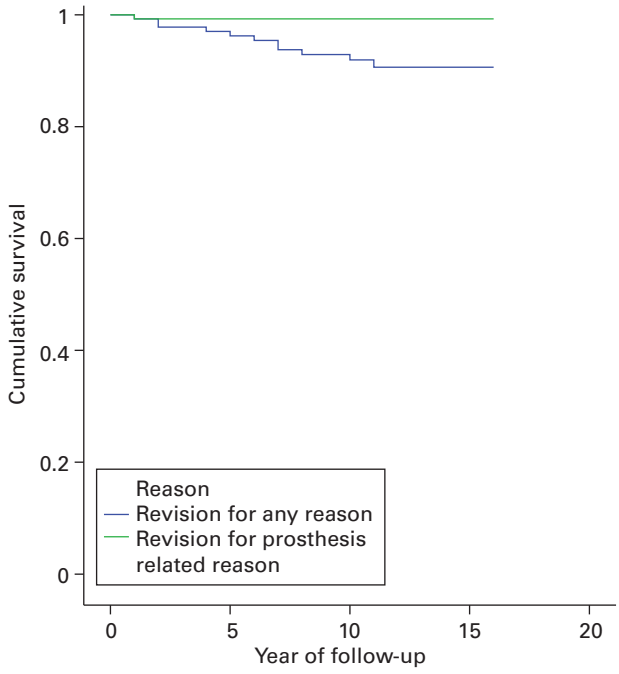

Fig. 1

Kaplan-Meier Estimates of Survival Function. Survival based on revisions for any reason and for prosthesis specific reasons. Revisions due to pain or disease progression were not considered prosthesis related. Five year survival based on revision for any reason: 96.2% (95% confidence interval (CI): 93.0 to 99.5%). Seven year survival based on revision for any reason: 93.8% (95% CI: 89.6 to 98.0%). Ten year survival based on revision for any reason: 91.6% (95%CI: 87.1 to 96.8%). 12 year survival based on revision for any reason: 90.6% (95%CI: 85.2 to 96.0%).

(CI).[27] Failure was defined as the removal of any component of the implant during the follow-up. A distinction was made between revision prosthesis and non-prosthesis related. Prosthesis related was due to component malposition/dislocation. Except for age, the data were not normally distributed. Pre- and post-operative data are represented with descriptive statistics. The median or mean and the range are presented as appropriate. The tibiofemoral angles were compared using the non-parametric Wilcoxon signed-rank test with a level of significance at $p < 0.05$. Data were analysed using SPSS software (SPSS 22.0, SPSS Inc., Chicago, Illinois).

Results

The mean follow-up was 11.7 years (10 to 15). Pre- and post-operative outcomes are summarised in Table II. In all, 77% of knees (n = 62) had a good or excellent clinical outcome score according to the KSS. The survival at 15 years with revision for any reason as the endpoint was 90.6% (95% CI 85.2 to 96.0) and prosthesis related revision was 99.3% (95% CI 97.9 to 100; Fig. 1). A total of 11 knees (8%) (138 knees at risk) underwent revision surgery after a mean follow-up of 5.7 years (0.5 to 11). In four patients the revision surgery was within four years post-operatively because of surgical error (n = 1; combination of malalignment femoral component and flexion-extension gap mismatch) or due to failure to adhere to the strict indication criteria for the Oxford UKA (n = 3) the details of which are reported in Table III. A total of seven knees were revised between five and 11 years follow-up: two because of consistent unexplained pain (1.5%) and five (3.6%) due to progression of osteoarthritis in the lateral compartment. There were no revisions due to infection, wear, implant fracture or loosening of the components.

Radiology

A total of 81 knees were available for radiological examination. Radiolucency was identified in 27.2% of all available UKAs. Complete physiological radiolucency (< 2 mm) was observed in five (6.2%) tibial components. In all, 15 (18.5%) tibial components had only partial physiological radiolucent lines. All these physiological radiolucencies (total 24.7%) in 20 knees were visible at year one post-operatively and remained unchanged in extent and thickness at later follow-up. In two knees (2.5%), pathological signs of radiolucency beneath the tibial component were observed. These arthroplasties were still not revised and functioning well at final (greater than ten years) follow-up. No radiolucency was found in relation to the femoral component.

Progression of medial facet patellofemoral joint osteoarthritis (PFJ-OA) as seen on axial patellar view in the presence of patellofemoral joint narrowing was observed in two non-symptomatic knees. The occurrence of lateral facet PFJ-OA was observed in two patients, of whom one knee in each patient was symptomatic and was revised. The

Table III. Details of revisions to primary total knee arthroplasty (TKA)

Revision	Indication for revision	Operative findings	Time to revision (yrs)	Procedure	Outcome
1	2nd bearing dislocation	Flexion-extension gap mismatch†, Malrotation femoral component	0.51	Primary TKA	Good
2	Pain	Insufficient ACL, Chondropathy lateral compartment*	2.06	Primary TKA	Good
3	Disease progression	Lateral compartment OA*, previous HTO	2.46	Primary TKA	Poor
4	Pain	PFJ-OA*	3.69	Primary TKA	Poor
5	Disease progression	PFJ-OA and lateral compartment OA	5.49	Primary TKA	Good
6	Pain	No cause found	5.74	Primary TKA	Good
7	Disease progression	Lateral compartment OA	6.8	Primary TKA	Good
8	Disease progression	Lateral compartment OA	7.49	Primary TKA	Good
9	Disease progression	Lateral compartment OA	7.82	Primary TKA	Good
10	Disease progression	Lateral compartment OA	10.16	Primary TKA	Good
11	Pain	No cause found	11.39	Primary TKA	Good

* Failure to adhere to the strict indication criteria for the Oxford unicompartimental knee arthroplasties
† Prosthesis related failure
ACL, anterior cruciate ligament; PFJ, patellofemoral joint; OA, osteoarthritis; HTO, high tibial osteotomy

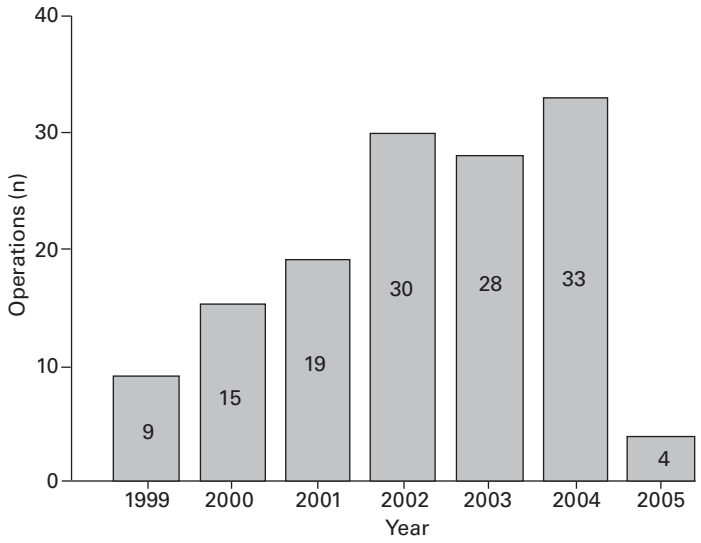

Fig. 2

Annual number of Oxford Phase III arthroplasties performed by the single surgeon.

mean tibiofemoral angle measured on weight-bearing short-length AP knee views at six months was 5.0° valgus, (-2 to 15) and decreased at final follow-up to 4.7° valgus (-6 to 16) (p = 0.001). Long-length standing radiographs were not available at the institution.

Discussion

The most important findings of this study were the excellent[28] long-term clinical outcome scores of the Oxford Phase III UKA with a cumulative survival rate with revision for any reason as endpoint of 90.6% (95% CI 85.2 to 96.0) at 15 years follow-up obtained in a district general hospital. Price et al[29] and Clement et al[30] also reported high medium-term (seven to ten year) survival rates. The first two years were considered as the learning curve period. These patients are included in the study. The average number of procedures that were performed annually in this series was 28 (Fig. 2). According to Liddle et al[31] 28 per year would account for a medium volume (eight to 30 per year). After the learning curve period in this study, high volumes were obtained annually. In another study Liddle et al[32] showed that low-usage surgeons tend to have high revision rates and recommend that at least 20% of their arthroplasties should be UKAs to achieve higher survival rates. The importance of high-volume units for the technically demanding Oxford arthroplasty was stressed by Koskinen et al[33] who reported high failure rates in their Finnish Arthroplasty Register study in low number surgeons/clinics. To our knowledge this is the first study, which describes the results of the Oxford Phase III UKA after a minimum of ten years follow-up for a single non-designer surgeon with large volume. Svärd[6] also described the long-term (mean 12.5 years; 10.1 to 15.6) results of the Oxford prosthesis (Phase I and II) but by a standard open procedure. Their ten-year cumulative survival was 95.0% (95% CI 90.8 to 99.3). The series by Svärd and Price[7] showed very few

revisions in the second decade after the index procedure and suggested that the implant is durable in this period after implantation. Recently, Pandit et al[34] reported similar long-term (mean 10.3 years; 5.3 to 16.6) outcomes in the designer's group of 1000 implants with a 15-year survival rate (with all implant-related re-operations considered as failures) of 91% (95% CI 83.0 to 97.9) and 79% of knees with a good or excellent clinical outcome score.[28]

The present study reports the outcome of patients with a long-term follow-up. We observed that functional recovery is almost reached after one year and does not improve significantly thereafter. This finding is also stated by Pandit et al.[35] When any surgery related factors are involved, revisions occur mostly within two years after primary surgery.[6,36,37] Late revisions in our series occurred due to the presence of symptomatic lateral compartment arthritis after a mean follow-up of 7.5 years (3.6%; Table III). Progression of lateral compartment OA is the most common cause of revision in our series and this corresponds with Pandit et al[11] and Price, Waite and Svärd.[38] Pandit et al[34] showed that 2.5% of their revisions were due to lateral compartment OA. Emerson and Higgins[10] reported 12.7% of total revisions including 7.3% (n = 4) of revisions due to lateral OA after a mean follow-up of 10.2 years in a series of 55 UKAs. They did not find any correlation between revision and post-operative alignment of the limb. On the other hand some similar studies report that the incidence of disease progression of the lateral compartment is low and even rare: Saldanha et al[39] reported 1.3%, Kim et al[12] reported 0.6% and Faour-Martín et al[40] reported none in their series. Overall, in the present study the revision rate for lateral compartment OA is slightly higher than previously reported. Apart from overcorrection into valgus in one case with minimal lateral compartment chondropathy pre-operatively, we do not have an explanation for this slightly higher revision rate.

Pre-existent PFJ-OA is considered not to be a contraindication for performing UKA. According to the designer group of the Oxford prosthesis this implant can be used for medial replacement even when PFJ-OA changes are present.[3] Kang et al[41] reported in their series of 195 knees that degenerative changes of the patellofemoral joint should not be considered a contraindication for medial Oxford UKA. They did not see significant difference in scores between those patients who had patellofemoral osteoarthritis preoperatively and those who did not. However, Beard et al[42] stated that the presence of lateral facet PFJ-OA might negatively influence the outcome of the UKA and that caution in these cases should be observed. We report two patients with symptomatic lateral facet PFJ-OA who were revised to TKA, one with poor and the other with good results. Two of the patients with progression of medial patellofemoral facet degeneration are still doing well after 11.3 and 12.3 years follow-up and we believe that the presence of medial facet PFJ-OA has no influence on the outcome of medial UKA. This report shows that the progression of symptomatic PFJ-OA in medial UKAs is rare and is supported by Weale et al.[43]

Dislocation of the mobile bearing in the Oxford knee primarily occurs shortly after implantation[44] as seen in our single case. It was the result of an error producing a mismatch in the extension and flexion gap and malposition of the components. Conversion to a standard condylar type TKA led to good clinical outcome. No revisions were performed due to deep infection, primary polyethylene wear, fracture of the bearing or loosening of the components. In contrast to the present study, the most common reason for revision in a series of 1819 UKAs from the Finnish Arthroplasty Register implanted between 1985 and 2003 as described by Koskinen et al[33] was aseptic loosening. As reported by others we also conclude that right indication criteria and a meticulous surgical technique are the key factors for success of the arthroplasty.[45]

When compared with previous studies a low incidence (27.2%) of radiolucency was found. Pandit et al[11] reported radiolucent lines in 70% of their UKAs (40% complete and 60% partial). From our experience we agree with previous authors that these radiolucent lines have no clinical relevance.[45] Our use of thorough pulsed lavage and a dry surgical field before cementing in the procedures might contribute to the low incidence of radiolucency we found. This is supported by the studies of Faour-Martín et al[40] and Clarius et al.[46] However, we acknowledge that the surgeon also undertook the fluoroscopic examination and this might be prone to bias.

Regarding the survival and clinical outcome scores the scores in this report are fairly similar to the scores presented by others. Overall results of medial UKA according to the KSS showed 96% excellent or good outcome for knees in the report by Faour-Martín et al,[40] compared with 79% and 77% in a report from Pandit et al[34] and the present study respectively. The mean Oxford Knee Scores were 40 and 42 in Pandit et al's[34] series and our series respectively. The mean age in these three reports is 59, 66 and 72 years and mean follow-up 10.4, 10.6 and 11.7 years, respectively. Survival was 96.3% (ten years), 91% (15 years) and 90.6 (15 years), respectively. The age and follow-up duration might be factors that explain the differences in outcome scores.

Short-term follow-up results of UKA[47] demonstrate predictably better results comparable with those of TKA, but longer follow-up data that make this comparison are not yet available. Liddle et al[32] showed better patient-reported outcomes measures (PROMS) in UKA compared with TKA in the short-term (six months) using data from a large national joint registry. They stated that the higher revision rate in UKAs compared with TKAs might be due to the fact that UKAs can be revised more easily despite possible better functional outcome in the longer term. Difference in revision rates may not be because of differences in functional outcomes alone. Clarification of risk factors for failure still need to be assessed in the near future. With

appropriate patient selection, prosthetic design and surgical technique a trained surgeon can achieve good outcomes in patients with UKA. Patients may experience a rapid recovery after UKA with use of the MIS technique.[48]

In conclusion, this independent prospective study showed a high survival rate of the Oxford Phase III UKA performed by a single surgeon with good to excellent outcome scores. The major complication rate was similar to other reports after a minimum of ten years follow-up. In our opinion excellent, durable and reproducible results can be expected for this minimally invasive surgical procedure in the long-term with appropriate case selection. The Oxford Phase III prosthesis has proven to be a reliable implant for patients with anteromedial OA and can be recommended as long as the strict indications for UKA are observed.

Take home message:

This independent prospective study showed a high survival rate of the unicompartmental knee prosthesis performed by a single surgeon with a low major complication rate and when strict indication criteria are followed, excellent, durable and reliable results can be expected for this minimally invasive surgical procedure in the long-term.

Author contributions:
L. A. Lisowski: Interpretation of data, Collection of data, Drafting, writing and revising the manuscript.
L. I. Meijer: Collection of data, Analysis and interpretation of data, Statistical analysis, Revising the manuscript.
M. P. J. van den Bekerom: Interpretation of data, Revising the manuscript.
P. Pilot: Analysis and interpretation of data, Revising the manuscript.
A. E. Lisowski: Surgeon, Concept and design, Interpretation of data, Drafting and revising the manuscript.

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1. Malon, M. (2015) Competitive Review of Lateral OA.[Unpublished Report] Data on file.
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1. Price, A., Svard, U. A Second Decade Lifetable Survival Analysis of the Oxford Unicompartmental Knee Arthroplasty. *Clinical Orthopedics and Related Research.* 469(1): 174-9, 2011.

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