A commentary by Michael S. Reich, MD, and Michael R. Baer, MD, is linked to the online version of this article at jbjs.org.

Revision Following Cemented and Uncemented Oxford-III Primary Medial Unicompartmental Knee Replacements

A 19-Year Analysis from the New Zealand Joint Registry

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Background: Oxford-III unicompartmental knee replacements (UKRs) are among the most commonly used prostheses to treat isolated medial compartment osteoarthritis (OA). However, the best mode of implant fixation for primary UKRs remains a source of debate. The hypothesis of this study was that the biologically superior fixation of uncemented Oxford-III primary UKRs would translate into a lower revision rate when compared with cemented Oxford-III primary UKRs used to treat isolated medial compartment OA.

Methods: Data on all Oxford-III primary UKRs (n = 8,733) completed for isolated medial compartment OA from January 2000 to December 2018 were obtained from the New Zealand Joint Registry (NZJR). Revision rates were documented for each fixation type and analyzed for associations with patient sex and age at surgery. A multivariate Cox proportional-hazards analysis was completed to determine if type of fixation was an independent risk factor for revision of Oxford-III UKRs.

Results: Statistical analysis revealed a >1.8-fold greater revision risk for cemented Oxford-III UKRs compared with uncemented Oxford-III UKRs (p = 0.001) when considered independently of other risk factors. Furthermore, compared with uncemented fixation, cemented fixation was associated with a 2.9-fold (p < 0.001) increase in revision risk for women <65 years old and a 1.7-fold (p = 0.008) increase in revision risk for men 55 to 74 years old. There was no significant difference in the risk of revision between fixation methods for women ≥65 years old and men ≥75 years old.

Conclusions: We found that the type of fixation was an independent risk factor for revision of Oxford-III UKRs used in the treatment of isolated medial compartment OA. Uncemented Oxford-III primary UKRs had superior implant survivorship in women <65 years old and men 55 to 74 years old. Age and sex are important factors to consider when determining the type of fixation for Oxford-III primary UKRs used to treat isolated medial compartment OA.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Unicompartmental knee replacement (UKR) is an effective treatment in patients with isolated medial compartment osteoarthritis (OA), providing better functional outcomes and faster recovery in the short term than total knee replacement[1-4]. However, the best mode of implant fixation in primary UKR has been a source of debate. Advocates of fully cemented UKR have stated that experienced surgeons can obtain good implant survivorship and clinical outcomes with appropriate patient selection criteria[5,6]. However, studies with further follow-up based on registry data have shown a substantial incidence of revision, most commonly due to pain and aseptic loosening of the components[7,8].

Revision of a UKR to a total knee replacement is not a straightforward procedure and has inferior outcomes compared with primary total knee replacement[9,10]. Therefore, modern uncemented prostheses were designed to enable

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osseointegration into the porous hydroxyapatite coating on the components in an attempt to limit the failure seen with cemented components. The uncemented Oxford-III UKR (Biomet UK) has entered clinical practice in some centers, with results showing biologically superior fixation with fewer radiolucencies compared with the cemented Oxford UKR (Biomet UK)[11-14]. In addition, uncemented Oxford-III UKRs require a shorter operating time and there is no risk of cementation errors, which can lead to pain secondary to impingement and accelerated wear[15,16].

Recent examination of national joint registries indicated that uncemented and cemented Oxford-III UKRs are among the most commonly used prostheses to treat isolated medial compartment OA[17,18]. The designs of the cemented and uncemented Oxford-III UKRs are essentially the same, with both having a fully congruent mobile bearing. Despite this, the medium to long-term revision rates have been higher for the cemented Oxford-III UKR[17-19]. Nonetheless, the majority of Oxford-III UKRs recorded in New Zealand have cemented fixation[17].

In a previous New Zealand Joint Registry (NZJR) analysis, Nugent et al.[20] compared revision rates among different methods of fixation of total knee joint replacements. We utilized a similar method to compare the rates of revision of fully cemented and uncemented Oxford-III primary UKRs performed for isolated medial compartments OA. The hypothesis of this study was that the biologically superior fixation of uncemented Oxford-III UKRs would translate into a lower revision rate when compared with cemented Oxford-III UKRs.

Materials and Methods

In this study, we retrospectively analyzed Oxford-III primary UKRs completed for isolated medial compartment OA that had been entered into the NZJR from January 2000 to December 2018. Regular audit has shown a capture rate of >95% from all hospitals that undertake joint replacement[17]. The UKRs were separated into 2 cohorts: cementless tibial and femoral components (uncemented group) and cemented tibial and femoral components (cemented group). Any patient who had had previous surgery on the index knee was excluded.

Patient-specific factors collected included sex, age at procedure, American Society of Anesthesiologists (ASA) physical status classification, and body mass index (BMI). ASA data have been recorded by the NZJR only since 2005 and BMI data, since 2010; thus, the sample sizes for comparisons including these data are reduced. Additionally, the mean yearly number of UKRs performed by the operating surgeon at the time of the index surgery was obtained as a surrogate for surgeon experience.

Revision was defined as a reoperation for any reason with the change of at least 1 component. The number of revisions for each group was obtained from the registry and used to calculate the overall rate of revision. This was expressed as the rate per 100 component years and was equivalent to the yearly rate of revision expressed as a percentage. The number of observed component years was defined as the sum of the number of years that each component had been in place. The revision rate per 100 component years is derived by dividing the number of prostheses revised by the observed component years multiplied by 100. This method accounts

TABLE I Baseline Characteristics of the Study Population According to Oxford-III UKR Fixation Group

	Cemented (N = 4,567)	Uncemented (N = 4,166)	P Value
Sex *(no. [%])*			<0.001*
F	2,254 (49.4%)	1,744 (41.9%)	
M	2,313 (50.6%)	2,422 (58.1%)	
Mean age (stand. dev.) at procedure *(yr)*	65.8 (9.5)	65.1 (9.5)	<0.001*
ASA physical status classification† *(no. [%])*			0.0049*
Class 1	509 (18.8%)	805 (19.4%)	
Class 2	1,790 (66.2%)	2,606 (62.9%)	
Class 3/4	403 (14.9%)	732 (17.7%)	
BMI‡ *(no. [%])*			<0.001*
<25 kg/m^2	202 (18.1%)	396 (12.0%)	
25-29 kg/m^2	456 (41.0%)	1,265 (38.4%)	
30-39 kg/m^2	418 (37.6%)	1,492 (45.3%)	
≥40 kg/m^2	37 (3.3%)	137 (4.2%)	
Surgeon experience *(no. [%])*			<0.001*
<10 UKRs/yr	2,861 (62.6%)	799 (19.2%)	
10-29 UKRs/yr	1,179 (25.8%)	1,649 (39.6%)	
≥30 UKRs/yr	527 (11.5%)	1,718 (41.2%)	

*Significant at the 0.05 level. †ASA data missing for some patients as this variable has been recorded in the NZJR only since 2005. ‡BMI data missing for some patients as this variable has been recorded in the NZJR only since 2010.

TABLE II Reasons for Revision of Cemented and Uncemented Oxford-III UKRs*

	Cemented		Uncemented			
Reason for Revision	No. (% of Revised Cemented UKRs)	% of Primary Cemented UKRs	No. (% of Revised Uncemented UKRs)	% of Primary Uncemented UKRs	P Value	Total No. (% of All Revisions)
Pain	174 (29.5%)	3.8%	21 (17.4%)	0.5%	0.006†	195 (27.4%)
Loosening						
Femoral	79 (13.4%)	1.7%	2 (1.7%)	0.05%	<0.001†	81 (11.4%)
Tibial	91 (15.4%)	2.0%	15 (12.4%)	0.4%	0.394	106 (14.9%)
Deep infection	18 (3.1%)	0.4%	6 (5.0%)	0.1%	0.274	24 (3.4%)
Fracture						
Femoral	1 (0.2%)	0.02%	2 (1.7%)	0.05%	0.077	3 (0.4%)
Tibial	6 (1.0%)	0.1%	6 (5.0%)	0.1%	0.008†	12 (1.7%)
Other	236 (40.0%)	5.2%	74 (61.2%)	1.8%		310 (43.6%)
Total*	590	12.9%	121	2.9%		711

*More than 1 reason is given for some revisions. †Significant at the 0.05 level.

for the number of years of postoperative follow-up when calculating the rates for comparison. These revision rates were compared between the cemented and uncemented groups. A survival curve was constructed with revision for any reason as the end point. The association between the sex and age of the patient at the time of the operation and the rate of revision was also determined for each analysis. In addition, the reasons for revision were examined and compared between fixation groups.

Statistical Analyses

Baseline covariates were compared between cohorts using an independent t test for continuous variables and a chi-square test for categorical variables. The rates of revision were calculated as the number of revisions per 100 component years. The 95% confidence intervals (CIs) for these rates were calculated using the standard Poisson approximation. Comparisons of these rates among patient groups were undertaken using the log-rank test. A Kaplan-Meier curve was generated to show cumulative revision-free rates over time. Patients who died during the follow-up period were considered to be censored in the construction of the Kaplan-Meier curve. Multivariate Cox proportional-hazards analysis was used to assess the independent relationship between fixation group and Oxford-III-prosthesis survivorship, with all-cause revision as the end point. This analysis was adjusted for confounding variables, including sex, age at procedure, ASA physical status classification, BMI, and surgeon experience expressed as the mean number of UKRs performed annually. A 2-tailed p value of ≤0.05 was considered to indicate significance.

Results

A total of 8,733 Oxford-III UKRs performed for isolated medial compartment OA were identified from the NZJR from January 2000 to December 2018. There were 4,567 UKRs with cemented fixation and 4,166 UKRs with uncemented fixation. A total of 711 revisions were performed. Baseline characteristics of the study population are displayed in Table I. The mean duration of follow-up was 9.2 years (range, 0.02 to 18.9 years) for cemented UKRs and 4.1 years (range, 0.01 to 13.7 years) for uncemented UKRs.

Table II shows the reasons for revision in each fixation group. Of note, a significantly greater proportion of the revisions in the cemented group compared with the uncemented group were due to pain (29.5% compared with 17.4%, $p = 0.006$) and aseptic loosening of the femoral component (13.4% compared with 1.7%, $p < 0.001$). Conversely, the percentage of revisions due to periprosthetic fracture of the tibia was significantly higher in the uncemented fixation cohort (1.0% in the cemented group compared with 5.0% in the uncemented group, $p = 0.008$). Differences between groups did not reach significance for any other reason for revision.

The revision rates for each Oxford-III fixation group are shown in Table III. Overall, the risk of revision was approximately double (chi-square test, $p < 0.001$) in the cemented

TABLE III Number of Oxford-III UKRs Revised According to Type of Fixation

Type of Fixation	No. Registered	No. Revised	Revision Rate Per 100 Component Years (95% CI)
Cemented	4,567	590	1.40 (1.29-1.52)
Uncemented	4,166	121	0.71 (0.59-0.85)*

*Significant at the 0.05 level.

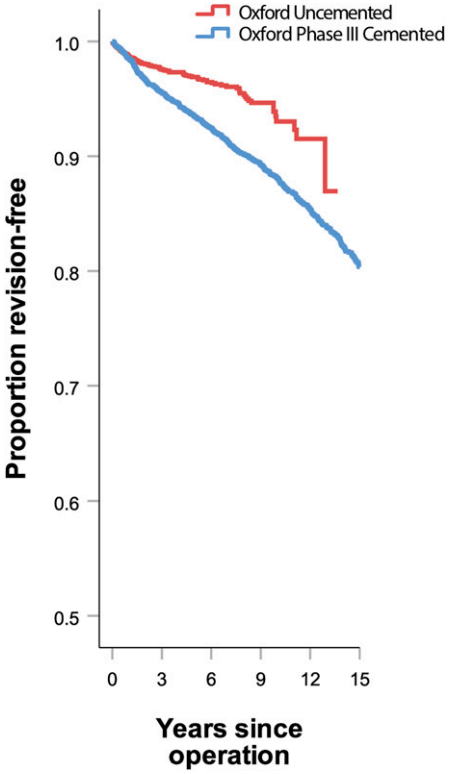

Fig. 1

Kaplan-Meier curves for the Oxford-III cemented UKR versus the Oxford-III uncemented UKR, with revision for any cause as the end point.

group compared with the uncemented group. Kaplan-Meier estimates of the revision-free rates over time showed a lower rate of revision in the uncemented group (Fig. 1). When considered independently of confounding variables in the multivariate Cox model (Table IV), the risk of revision was >1.8-fold (hazard ratio [HR] = 1.82, 95% CI = 1.27 to 2.60, p = 0.001) higher in the cemented cohort compared with the uncemented cohort. Other significant risk factors for revision of Oxford-III UKRs were an age of <55 years at the time of the procedure (HR = 2.06, 95% CI = 1.16 to 3.66, p = 0.014) and surgeon experience measured as UKRs performed annually (<10 UKRs: HR = 2.09, 95% CI = 1.33 to 3.28, p = 0.001; 10 to 29 UKRs: HR = 1.62, 95% CI = 1.05 to 2.50, p = 0.029) when the analysis was adjusted for confounding factors.

After adjustment for surgeon experience, the rate of revision in each fixation group was calculated for males and females within 4 age groups (Table V): <55 years, 55 to 64 years, 65 to 74 years, and ≥75 years. For females below the age of 65 years, the risk of revision of cemented UKRs was 2.9-fold higher (p < 0.001) compared with uncemented fixation. There was no significant difference in the rates of revision between cemented and uncemented fixation in females ≥65 years of age.

For males 55 to 74 years of age, the risk of revision of cemented UKRs was 1.7-fold higher (p = 0.008) compared with uncemented fixation. There was no significant difference in the revision rate between the 2 fixation groups for males <55 years old or those ≥75 years old.

Discussion

The overall rate of revision of Oxford-III UKRs for treatment of isolated medial compartment OA registered in the NZJR was low for both the cemented and the uncemented fixation group (Table III). This result is comparable with those in available reports[17-19,21]. Multivariate analysis indicated that the type of fixation is an independent risk factor for revision. When the type of fixation was stratified by the sex and age of the patient at the time of the procedure, the risk of revision following cemented fixation was 2.9-fold higher than that following uncemented fixation in females <65 years old and 1.7-fold higher in males 55 to 74 years old. This result confirms the findings of recent studies of registry data[17-19] and supports the initial hypothesis.

The primary reason for the above results is likely the superior biological fixation of uncemented UKRs[11-14] resulting in a reduced rate of aseptic component loosening. Radiolucent lines are a more common phenomenon in cemented UKRs[22,23], and represent a radiographic manifestation of the cement layer. There is considerable difficulty in determining whether radiolucent lines are physiological or indicative of aseptic loosening, which is commonly seen in cemented UKRs due to the cement layer[24]. Therefore, if a patient develops anteromedial pain and radiolucency, this may lead to an unnecessary revision

TABLE IV Multivariate Cox Proportional-Hazards Analysis of All-Cause Revision of Oxford-III UKRs

	HR (95% CI)	P Value
Sex (reference: male)	1.20 (0.87-1.65)	0.264
Age at procedure (reference: ≥75 yr)		
<55 yr	2.06 (1.16-3.66)	0.014*
55-64 yr	1.30 (0.78-2.17)	0.309
65-74 yr	1.17 (0.71-1.93)	0.537
ASA physical status classification (reference: Class 1)		
Class 2	0.80 (0.53-1.19)	0.272
Class 3/4	1.13 (0.66-1.94)	0.665
BMI (reference: <25 kg/m^2)		
25-29 kg/m^2	1.11 (0.68-1.82)	0.670
30-39 kg/m^2	1.02 (0.62-1.68)	0.954
≥40 kg/m^2	0.60 (0.198-1.79)	0.356
Type of fixation (reference: uncemented)		
Cemented	1.82 (1.27-2.60)	0.001*
Surgeon experience: (reference: ≥30 UKRs/yr)		
<10 UKRs/yr	2.09 (1.33-3.28)	0.001*
10-29 UKRs/yr	1.62 (1.05-2.50)	0.029*

*Significant at the 0.05 level.

TABLE V Rate of Revision of Oxford-III UKRs According to Fixation Type, Sex, and Age Group, Adjusted for Surgeon Experience

Age, Sex, Fixation	No. Registered	No. Revised	Revision Rate per 100 Component Years (95% CI)
<55 yr, F			
Cemented	317	79	2.67 (2.10-3.30)
Uncemented	298	6	0.48 (0.15-0.98)*
<55 yr, M			
Cemented	224	43	2.08 (1.50-2.80)
Uncemented	282	19	1.59 (0.96-2.49)
55-64 yr, F			
Cemented	734	127	1.81 (1.51-2.15)
Uncemented	575	16	0.62 (0.36-1.01)*
55-64 yr, M			
Cemented	834	125	1.51 (1.26-1.80)
Uncemented	852	24	0.70 (0.45-1.04)*
65-74 yr, F			
Cemented	698	76	1.13 (0.88-1.41)
Uncemented	580	17	0.73 (0.41-1.14)
65-74 yr, M			
Cemented	833	79	1.01 (0.79-1.25)
Uncemented	858	19	0.54 (0.33-0.85)*
≥75 yr, F			
Cemented	505	39	0.98 (0.70-1.34)
Uncemented	291	12	0.98 (0.51-1.72)
≥75 yr, M			
Cemented	422	22	0.69 (0.42-1.02)
Uncemented	430	8	0.54 (0.23-1.06)

*Significant at the 0.05 level.

procedure, as the radiolucency may not be the source of pain[25]. Liddle et al.[26] showed that anteromedial pain often resolves spontaneously in the first postoperative year as a result of bone remodeling. Abolishing the cement layer also reduces the number of potential interfaces that can fail, thereby decreasing the rate of aseptic loosening of components[11-14]. Finally, technical errors in cementation, such as inadequate cementation, presence of loose fragments, or cement extrusion, can cause pain secondary to impingement[15,16] and an elevated rate of aseptic loosening of components[27], both of which may lead to subsequent revisions. Higher rates of technical errors in cementation and/or misinterpretation of radiolucent lines are more likely to occur and lead to revision after procedures performed by low-volume surgeons[28], such as those performing most Oxford-III cemented UKRs in New Zealand (Table I). This is evidenced by the significantly greater percentage of revisions attributed to pain and aseptic loosening of the femoral component in the cemented Oxford-III UKR cohort (Table II).

Notably, there was no difference in the revision rate between cemented and uncemented fixation in females ≥65 years old and males ≥75 years old. This finding is consistent with total hip and knee replacement registry data from New Zealand[20,29]. The association of impaired angiogenesis with osteoporosis in elderly individuals reduces the biomaterial osseointegration of the prosthesis, leading to poor-quality uncemented fixation[30]. Furthermore, introduction of uncemented components requires substantial impaction,

TABLE VI Comparison of Percentages of Oxford-III Cemented and Uncemented UKRs in Different National Joint Registries

National Joint Registry	Percentage	
	Cemented	Uncemented
New Zealand	52.3	47.7
Australia	71.7	28.3
Norway	70.5	29.5
England, Wales, Northern Ireland and the Isle of Man	76.0	24.0

increasing the risk of periprosthetic fracture in osteoporotic elderly patients with softer, poorer-quality bone[11,31]. Additionally, Seeger et al.[32] demonstrated a lower load to fracture during implantation of the tibial component in UKRs with uncemented fixation compared with cemented fixation. These factors may explain the significantly increased proportion of revisions due to periprosthetic tibial fractures in the uncemented Oxford-III UKR group in our study (Table II) and explain the similar overall revision rates of uncemented and cemented Oxford-III UKR prostheses in the elderly population.

A criticism of registries is that the orthopaedic practice within a catchment area may be skewed toward one procedure. This was demonstrated in other national joint registries, such as the Australian Orthopaedic Association National Joint Replacement Registry[18], the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man[19], and the Norwegian Arthroplasty Register[21], which are skewed toward cemented fixation of UKRs. In contrast, the distribution of cemented and uncemented UKRs is relatively balanced in the NZJR[17] (Table VI). Furthermore, the NZJR prospectively collects data, with regular auditing confirming a capture rate of >95% from all hospitals that undertake joint replacement[17]. Finally, our analysis accounted for confounding variables, including sex[33,34], age at the procedure[33,34], ASA physical status classification[35], BMI[36,37], and surgeon experience[28,35]. Although these variables were analyzed, commentary on their effect on UKR revision rates is outside the scope of the current study. The balanced distribution of fixation techniques for UKRs, high capture rate of prospectively collected data, and consideration of confounding variables strengthen the validity of this study.

This study has limitations. NZJR data and the specifics of our revision analysis may not be transferable to other countries with different reporting methodologies. Also, all-cause revision was the primary end point of the present study; however, not all patients who have problems following UKR undergo revision. Future correlation with patient-reported outcome measures may help to identify additional differences in some of these factors.

In conclusion, after adjustment for confounding variables, we found that the type of fixation was an independent risk factor for revision of Oxford-III primary UKRs used for the treatment of isolated medial compartment OA. Uncemented fixation of Oxford-III primary UKRs resulted in superior implant survivorship in females younger than 65 years and males 55 to 74 years of age. Therefore, age and sex are important factors to consider when determining the type of fixation for Oxford-III primary UKRs used to treat isolated medial compartment OA. ■

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