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International multi-centre survivorship analysis of mobile bearing total knee arthroplasty

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Abstract We retrospectively reviewed the experience of a large international multi-centre study of primary total knee arthroplasty with mobile bearing design and modifications of the tibial component to allow for bicruciate preservation, posterior cruciate retention, or sacrifice. Twenty-seven surgeons performed 4,743 total knee replacements between 1981 and 1997. Implants inserted were 324 that retained both cruciate ligaments, 2,165 that retained the posterior cruciate, and 2,254 that sacrificed both cruciates. The patella was resurfaced in 2,838 and unresurfaced in 1,905. With failure defined as revision or reoperation for any reason, the overall survivorship was 79% at 16 years' follow-up. Revision occurred in 259 (5.4%) knees out of the entire cohort. The risk adjusted rates of failure were higher in females, younger patients, osteoarthritis, post-traumatic arthritis, and in patients who had a meniscal bearing prosthesis or patellar resurfacing. The most common cause of revision was bearing-related issues including chronic instability, bearing subluxation, bearing dislocation, or bearing wear in 2.3%.

Résumé Nous avons revu rétrospectivement une série multicentrique de prothèses totales primaires de genoux avec plateaux mobiles et pièce tibiale permettant le sacrifice ou la conservation d'un ou des deux ligaments croisés. Entre 1981 et 1997, 4743 prothèses ont été faite par 27 chirugiens. Les implants utilisés étaient pour 2254 sans ligaments croisés, pour 2165 avec croisé postérieur et pour 324 avec conservation des 2 croisés. La rotule a été resurfacée 2838 fois. Avec l'échec défini par la reprise chirurgicale, la survie était de 79% à 16 ans de recul. Une reprise a été faite 259 fois (5,4%). Le risque d'échec était plus grand chez les femmes, les patients jeunes, en cas d'arthrose primaire ou post traumatique et chez les patients avec une prothèse à ménisques mobiles ou avec une rotule prothèsée. Les causes les plus fréquentes de révision étaient l'instabilité chronique, la subluxation ou la luxation des plateaux mobiles et leur usure.

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Introduction

Mobile bearing was originally introduced with the Oxford knee in 1977, which sought to improve articular congruity for improved wear characteristics using a spherical, congruous articulation while diminishing implant constraint with a floating surface [1, 26, 27, 36]. The Low Contact Stress (LCS.) knee prosthesis (DePuy, Warsaw, IN, USA), the subject of this outcome study, is a mobile bearing design with modifications of the tibial component to allow for bicruciate preservation (BCR), posterior cruciate retention (PCR), or sacrifice (RP) [7, 8]. The design geometry of these implants has remained unchanged since the original implantation in 1977. However, substantial differences in design concept arise from the tibia component modifications. For example, preservation or sacrifice of the cruciate ligaments may offer significant differences in clinical and kinematic performance. The surgical technique with the tibia-cutfirst approach and initial flexion-block spacing has remained the standard at centres using this prosthesis [12, 29, 30, 54].

The aim for highly conforming mobile bearing implants to improve the durability of total knee arthroplasty by potentially reducing polyethylene wear and osteolysis have been desirable objectives [2, 34]. However, several authors have raised the concern that the introduction of additional complexity through the use of a moving bearing will also introduce new modes of device-related failure [6, 58]. The primary purpose of this study was to retrospectively evaluate the experience of a large multi-centre trial with a mobile bearing prosthesis to determine the occurrence of revision and failure. No manufacturing or design changes were made to the implants during the course of this experience. A minimum of a five-year follow-up was chosen as we wanted to study causes of early failure of the mobile bearing prosthesis likely to occur during this period. The tibial implant modifications offered the potential of evaluating different design concepts with an implant of similar design geometry. Specifically, all femoral components were identical and the tibial articulating surface geometries were matched to the femoral prostheses. Additionally, we wanted to assess the influence of independent variables such as age, sex, diagnosis, and type of fixation on the results of this mobile bearing total knee arthroplasty. We wanted to know if the rates of failure compared unfavourably with those in the literature. While we recognise that detailed outcome analysis includes the use of clinical assessment tools and radiographic follow-up studies, we determined that this amount of data accrual would not be feasible for the large number of patients surveyed. This international experience includes patients from diverse backgrounds with many different native languages spoken. We are unaware of a validated outcome tool that would cover the spectrum of these differences. As patients were not evaluated prospectively, we questioned whether clinical information or radiographs could be recovered to the level found in some national joint registries. However, we believe that important knowledge regarding implant safety and performance could be gleaned from the methodology of this study.

Materials and methods

Methods

This study included the results of 27 surgeons representing ten nations from around the world with extensive experience using the LCS mobile bearing prosthesis. Inclusion criteria were all primary total knee arthroplasties performed between 23 February 1981 and 1 January 1997. Exclusion criteria were unicondylar knee replacements, revision total knee arthroplasties, AP Glide configuration, and the use of all polyethylene tibial components. It is understood that these were consecutive case series, and that each surgeon was reporting on all mobile bearing prostheses inserted, although there may have been other implants used for certain complex or conversion cases that required elements such as stems or configurations that were never available with this system. For each surgeon, there were no exclusions of mobile bearing implants for any reason during the periods of study. Furthermore, each surgeon independently selected the specific implant design concept for his patients and this may have reflected his personal experience, philosophy, or bias. No rules were made for surgeon choice, and no centres were eliminated because of these choices.

The surgical procedure was standardised with initial ligament balancing followed by resection of the proximal tibia such that the surface was made perpendicular to the mechanical axis of the tibia in the coronal plane and parallel to the native tibial joint surface in the sagittal plane [9, 10]. The flexion gap was prepared using an anterior cortical reference and careful spacing to allow preservation of the anterior and posterior cruciate ligaments, retention of the posterior cruciate ligament, or sacrifice of both ligaments. The distal femur was then resected to create a femorotibial alignment of five to seven degrees in the coronal plane. The femoral component design requires a 15° sloped cut of the distal femoral surface in the sagittal plane. The patella was resurfaced with a mobile bearing metal-backed patella prosthesis or left unresurfaced based on the individual experience of the surgeon.

Retrospective data collection included those elements required for the survivorship analysis including the dates of the operative procedure, last follow-up, death, and failure. Failure was defined as revision or reoperation for any reason and included any procedure in which the tibial tray, femoral component, bearing or patellar component was exchanged or replaced with another device as well as periprosthetic fracture, patellar fracture, or ligamentous injury. Demographic data included age, sex, diagnosis, and extremity involved. It was noted whether the type of device used was bicruciate, meniscal bearing, rotating platform, or resurfaced patella, and whether fixation was either cementless or cemented. Pain, walking, or functional outcome questions were not recorded as these were not available using a standardised method. Range of motion, however, was recorded as this is considered to be quantifiable and routinely performed in most centres.

Table 1 Cumulative collection of patients entered each year into the survivorship analysis

Year of surgery	Frequency	Percentage	Cumulative frequency	Percentage
1981	20	0.42	20	0.42
1982	28	0.59	48	1.01
1983	40	0.84	88	1.86
1984	44	0.93	132	2.78
1985	129	2.72	261	5.50
1986	210	4.43	471	9.93
1987	275	5.80	746	15.73
1988	351	7.40	1,097	23.13
1989	193	4.07	1,290	27.20
1990	243	5.12	1,533	32.32
1991	323	6.81	1,856	39.13
1992	343	7.23	2,199	46.36
1993	530	11.17	2,729	57.54
1994	709	14.95	3,438	72.49
1995	881	18.57	4,319	91.06
1996	424	8.94	4,743	100.00

Table 2 Survivorship is presented at yearly intervals for the overall group identifying those lost to follow-up and those who died at each interval

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17–19
Estimate(%)	100	99	98	97	97	96	95	95	94	92	91	89	87	83	82	79	–
No. knees entered	4,743	4,290	3,962	3,605	3,176	2,745	2,137	1,529	1,158	841	640	435	270	148	80	36	12
Revised	41	45	26	16	18	24	13	17	15	8	13	9	8	2	2	2	0
Died or last follow-up	412	283	331	413	413	584	595	354	302	193	192	156	114	66	42	22	12

Statistical analysis

Statistical analysis focused on survivorship using both Cox proportional hazards analysis and life table methods. Definitions of failure included: all causes of revisions including revision due to aseptic loosening. Patients who died or had not failed at the time of their last clinic visit were considered censored. The Cox proportional hazards survival analysis is an ideal instrument for looking at multiple predictor variables because all variables included in the model adjust for each other. In other words, the estimates associated with one variable changing from one level to another are calculated with all other variables held constant at their average value. Hazard ratios are reported for predictor variables that are statistically significantly related to changes in survivorship. The life table survivorship method was used to provide survivorship estimates, 95% confidence intervals around those estimates, and to make univariate comparisons using the log-rank test. Unlike the Cox analysis, life table univariate comparisons are not adjusted by other predictor variables. Adjusted Cox survivorship estimates were not reported because adjusted estimates are sometimes very different from unadjusted estimates. In almost all the orthopaedic literature, unadjusted estimates are reported. For ease of comparison, the authors felt that unadjusted estimates should be exclusively reported. Dorey and Amstutz suggested that survival estimates be reported only when the effective sample size is greater than 20 cases and that guideline is followed in this report [18]. Relationship of the patient's age, diagnoses, gender, device configuration, and cement status on survival were assessed using the Cox model to perform a multi-factor analysis of survival of the implants. The log-rank test was used to compare the survival curves of the differing surgical techniques. Cox regression analyses provided hazard ratios, with 95% confidence intervals relative to the reference category, for significantly related predictor variables. The Chi-squared test was used for categorical analysis. SAS statistical software (version 8.2) was used for the statistical analyses.

Results

There were 4,743 total knee replacements performed between February 1981 and January 1997 with an average overall follow-up of 5.7 years (Table 1). Of the entire cohort, 4,192 had either died or had not failed at the time of their last clinic visit (censored in the survival analysis; (Table 2) There were 1,437 males and 3,306 females. There were 324 bicruciate-retaining implants (BCR); 2,165 posterior cruciate-retaining implants (PCR), and 2,254 rotating platform (RP) implants inserted. The patella was resurfaced in 2,838 and unresurfaced in 1,905. By diagnosis, 77.3% were osteoarthritic, 19% rheumatoid, 2.6% post-traumatic, and 1.1% other. The overall average age at surgery was 68 years. The mean age for the PCR and RP patients was 68 while that for BCR was 62 years. By diagnosis, the mean age was 69 for osteoarthritics, 64 for the other group, and 62 for post-traumatic and rheumatoid patients. The knee was right-sided in 52.2% and left-sided in 47.8% (Table 3).

Overall, 69% of all knees had cementless fixation while 31% had at least one component, either femur and tibia or just the tibia, fixed with cement. The patella was fixed cementless in 77% of cases. By implant type, 86% of patella components were implanted without cement with BCR; 74% in the PCR; and 80% in the RP (Table 4). The overall range of motion at last follow-up examination was

Table 3 Breakdown of implant types by diagnosis. *OA* osteoarthritis, *OT* other, *PT* post-traumatic arthritis, *RA* rheumatoid arthritis, *BCR* bicruciate retaining, *PCR* posterior cruciate retaining, *RP* rotating platform

Tibia type	Diagnosis																				
	OA				OT				PT				RA				All				
	Cement				Cement				Cement				Cement				Cement				
	No		Yes		No		Yes		No		Yes		No		Yes		No		Yes		All
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
BCR	135	67.5	65	32.5	4	100.0			6	100.0			101	88.6	13	11.4	246	75.9	78	24.1	324
PCR	1,214	77.7	349	22.3	20	76.9	6	23.1	29	82.9	6	17.1	359	66.4	182	33.6	1,622	74.9	543	25.1	2,165
RP	1,172	61.6	731	38.4	15	65.2	8	34.8	69	84.1	13	15.9	141	57.3	105	42.7	1,397	62.0	857	38.0	2,254
All	2521	68.8	1,145	31.2	39	73.6	14	26.4	104	84.6	19	15.4	601	66.7	300	33.3	3,265	68.8	1,478	31.2	4,743

Table 4 Breakdown of patellar resurfacing by diagnosis, fixation and tibial implant

Tibia type	Diagnosis																											
	OA				OT				PT				RA				All					All						
	Cement				Cement				Cement				Cement				Cement					Cemented patellar						
	No		Yes		No		Yes		No		Yes		None		Yes		No		Yes		All			No		Yes		All
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	*n*	%	*n*	%	*n*	%	*n*
BCR	135	67.5	65	32.5	4	100.0			6	100.0			101	88.6	13	11.4	246	75.9	78	24.1	324	104	32.1	189	58.3	31	9.6	324
PCR	1,214	77.7	349	22.3	20	76.9	6	23.1	29	82.9	6	17.1	359	66.4	182	33.6	1,622	74.9	543	25.1	2,165	792	36.6	1,012	46.7	361	16.7	2,165
RP	1,172	61.6	731	38.4	15	65.2	8	34.8	69	84.1	13	15.9	141	57.3	105	42.7	1,397	62.0	857	38.0	2,254	1,009	44.8	997	44.2	248	11.0	2,254
All	2,521	68.8	1,145	31.2	39	73.6	14	26.4	104	84.6	19	15.4	601	66.7	300	33.3	3,265	68.8	1,478	31.2	4,743	1,905	40.2	2,198	46.3	640	13.5	4,743

110° and was similar for each of the implant types. For the "other" group, the overall range of motion was 104° with 117° for the BCR and 98° for the RP subgroups.

By device type, there were significant differences in diagnosis comparing all three implants. Overall, 62% of BCRs were performed in patients with osteoarthritis, compared with 72% for PCR and 84% for RP (Chi-squared $p<0.001$). Concurrently, 35% of BCRs, 25% of PCRs, and 11% of RPs were performed in patients with rheumatoid arthritis (Chi-squared $p<0.001$). For gender, the BCR (71% female) and PCR (74% female) groups had higher percentages of females than the RP (65% female) group (Chi-squared $p<0.001$).

With failure defined as revision for any reason, the life table survivorship was 79% (95% CI: 74% to 84%) at 16 years' follow-up. Of the entire cohort of patients, this included a total of 259 (5.4%) failures by revision for any reason (Table 5). By device type, the 14-year life table survivorship for BCR implants was 79%; PCR implants 82%; and RP knees 87% (Fig. 1). When we look at the life table survivorship rates at ten years' follow-up, the comparison is 89% for BCR, 91% for the PCR, and 94% for the RP implants. The overall 14-year life table survivorship for cementless fixation was 83% and for cemented fixation 84%. The life table survivorship of knees that had patellar resurfacing when considering all causes of failure was 80% at 14 years, while in the unresurfaced patellar group, survivorship was 91% at 13 years. The life table survivorship of the patella implants with failure or revision of patella for any reason was 98.6% at 15 years.

The overall life table survivorship for osteoarthritic patients was 80.7% at 15 years, while that for rheumatoid patients was 84.3% (NSD; Fig. 2). By device type, survivorship was similar for the diagnosis of osteoarthritic and rheumatoid, except in the group of PCRs, which showed a trend toward greater survivorship of rheumatoid patients over osteoarthritics (89.6% vs. 83.8%, log-rank $p=0.086$). For osteoarthritics, the rotating platform design performed substantially better than either the PCR or BCR at 13 years (88.3% survivorship; log-rank $p<0.01$). However, for the rheumatoids, there was no significant difference amongst device groups.

The following variables were investigated in the Cox model: patient's age, diagnoses, gender, device configuration, and cement status. Every variable was statistically significant at the 1% level except for cement. Interpretation of the hazard ratios indicate that PCRs are 1.5 times and BCRs are 2.2 times more likely to fail compared with RP implants. Patients with osteoarthritis or post-traumatic arthritis are 1.8 times more likely to fail compared with rheumatoid arthritis and the "other" group. Patients with patella resurfacing were 1.8 times more likely to be revised compared with patients with patella non-resurfacing. Females are 1.5 times more likely to fail than males. For each year increase in age at the time of primary operation, the risk of failure goes down by 2.1% (Table 6).

The most common cause of revision was bearing-related issues (2.3%), including chronic instability, bearing sub-

Table 5 Causes of implant failure by implant type including revision of metal component or polyethylene tibial insert(s)

	Tibia type												All			
	BCR				PCR				RP							
	Revised				Revised				Revised				Revised			
	Metal	No	Poly only	All	Metal	No	Poly only	All	Metal	No	Poly only	All	Metal	No	Poly only	All
	n	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
Rev category		284		284		2,023		2,023		2,177		2,177		4,484		4,484
Aseptic loosening	20			20	23		1	24	18			18	61		1	62
Infection	4			4	9			9	7			7	20			20
Instability	1			1	14		6	20	1		5	6	16		11	27
Insufficient surgery	4			4	10			10	8		1	9	22		1	23
Other					1			1	2			2	3			3
Other biological reasons					1			1	4		1	5	5		1	6
Patella problems	3			3			7	7	17		1	18	20		8	28
Polyethylene					14		21	35	1		4	5	15		25	40
Tibial bearing problem	4		3	7	9		21	30	2		5	7	15		29	44
Trauma			1	1	5			5				5			1	6
All	36	284	4	324	86	2,023	56	2,165	60	2,177	17	2,254	182	4,484	77	4,743

luxation, bearing dislocation, or bearing failure with polyethylene wear. Aseptic loosening was seen in 1.3% of patients. Patella-related failures were seen in 0.5% of cases and included bearing failure, component malposition on insertion, or component subluxation. Two patients out of the entire cohort had revision of a previously unresurfaced patella. Infection was identified in 0.4% of patients, while other rare causes of reoperation included trauma, arthrofibrosis, and unknown aetiology in 0.33%.

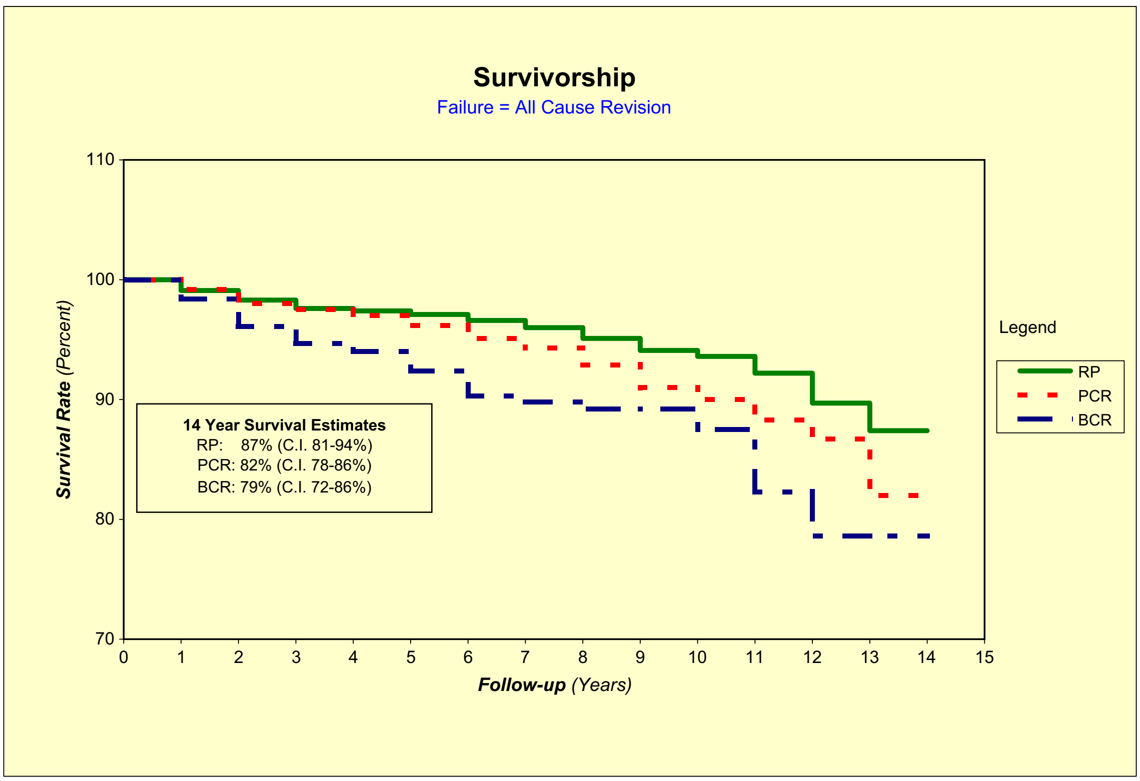

Fig. 1 Survivorship curves for all reasons for revision for the three tibial components: bicruciate-retaining (*BCR*), posterior cruciate-retaining (*PCR*), and rotating platform (*RP*)

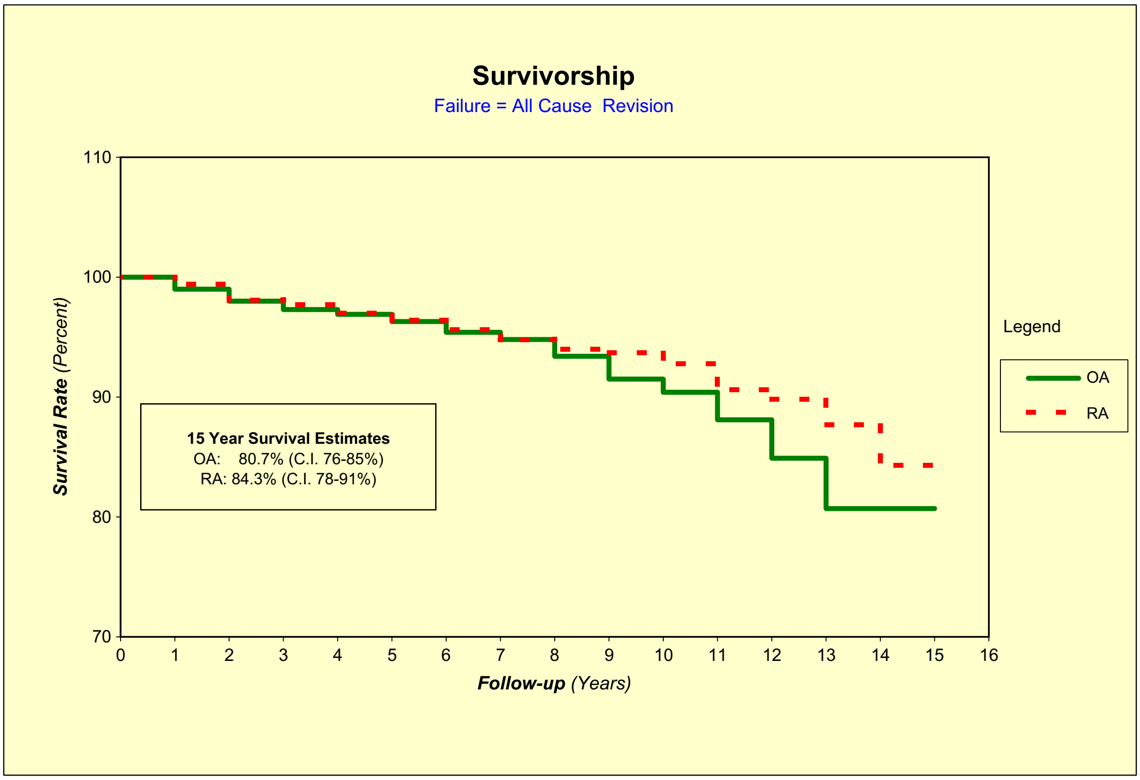

Fig. 2 Survivorship curves for all reasons for revision in the pathology groups OA (osteoarthritis), RA (rheumatoid arthritis), PT post-traumatic arthritis, and OT other group

The overall survivorship at 16 years for aseptic loosening was 95% (CI: 91–98%). By device type, aseptic loosening (Fig. 3) and sepsis were highest in the BCR group with 6.1% and 1.2% respectively. The highest failure group for bearing-related problems was the posterior cruciate retaining implant with 3.9% overall. This was compared with the BCR group with 2.4% and the RP group

Table 6 Cox proportional hazards regression significant variables, degrees of freedom (*DF*), hazard ratio descriptions, Chi-squared values and *p* values, hazard ratios, and 95% confidence intervals. Linear hypothesis testing for significant differences from 0 for any of the three tibial types

Cox proportional hazards regression hazard ratios						
Variable	DF	Interpretation of hazard ratios	Chi-squared	Pr>ChiSq	Hazard ratio	95% Hazard ratio confidence limits
tib_PCR	1	Patients with PCRs are 1.5 times as likely to fail compared with those with RP	8.5967	0.0034	1.552	1.157 2.081
tib_BCR	1	Patients with BCRs are 2.2 times as likely to fail compared with those with RP	14.0926	0.0002	2.188	1.454 3.294
dx_OA	1	Patients diagnosed with OA or PT are 1.8 times as likely to fail compared with those with RA and others	13.0781	0.0003	1.839	1.322 2.558
patcomponent	1	Patients with patella components are 1.8 times as likely to fail compared with those with no patella	13.4623	0.0002	1.814	1.320 2.494
Age	1	For each 1 year increase in age, the risk of failing goes down by 2.1%	15.4671	<.0001	0.979	0.968 0.989
Sex	1	Females are 1.5 times as likely to fail compared with males	7.1112	0.0077	1.513	1.116 2.051

Linear hypotheses testing results			
Label	WaldChi-Square	DF	Pr>ChiSq
No_tib	15.4818	2	0.0004

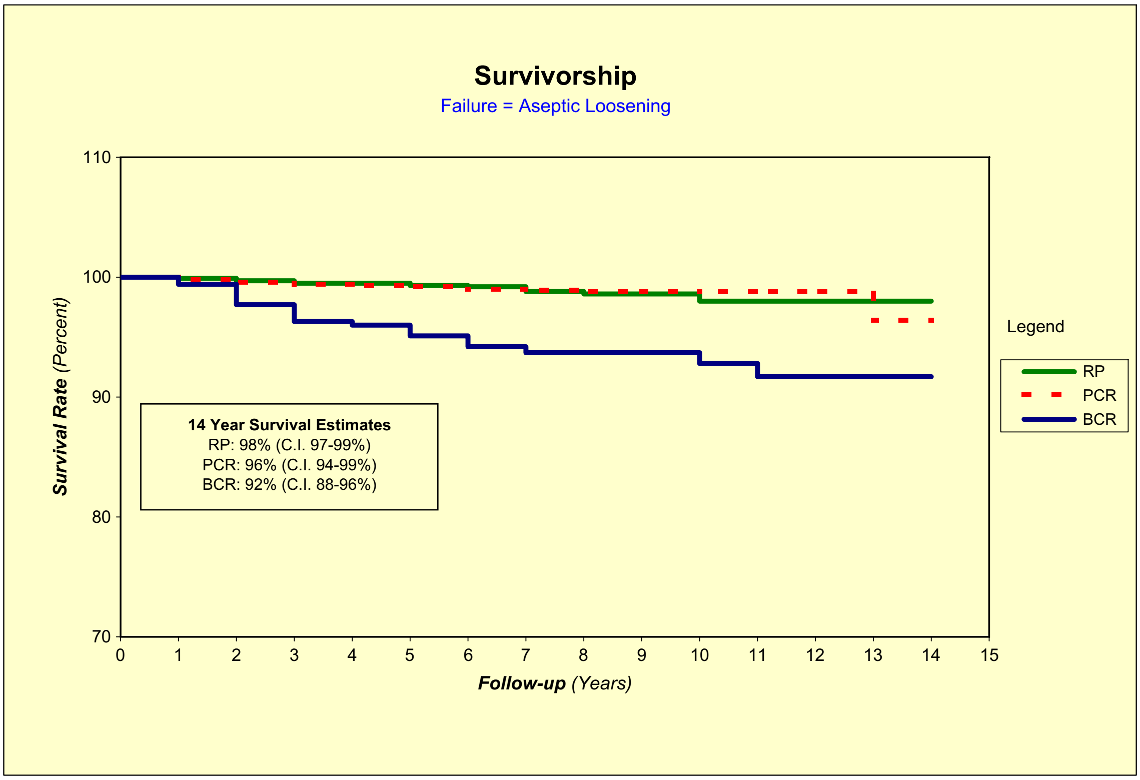

Fig. 3 Survivorship curves for aseptic loosening of cementless fixation of the tibial components BCR, PCR, and RP for all diagnoses

with 0.8% failures. The patellar failure rates were under 1% for all three implant types.

Discussion

Total knee arthroplasties with well-designed fixed-bearing prostheses have provided long-term fixation with prosthetic revision rates of 4 to 13% and survival rates of 85 to 95% with 10 to 23 years' follow-up depending upon the inclusion criteria [5, 15, 17, 22, 25, 31, 35, 38–40, 42, 43, 45, 48–52, 55, 56, 60]. Recent studies comparing posterior cruciate preservation or sacrifice in patients undergoing bilateral total knee arthroplasties have failed to show substantial differences in their clinical rating scores or functional outcome [4, 19, 53]. Furthermore, most published clinical reviews retrospectively evaluate a prosthetic device or surgical technique from a small group of surgeons over a period of time, and there appears to be little advantage of a specific approach, regardless of fixation or implant design. Many of these studies lack the statistical power to produce a conclusive answer, particularly if implants are inserted by expert surgeons.

Callahan et al. evaluated the results of 9,879 tricompartmental knee replacements for 130 publications using a meta-analysis. In that group, the mean age was 65 years, with 72% of patients being women, and 63% having osteoarthritis. The postoperative global scores were statistically better with posterior cruciate retention compared with posterior cruciate sacrifice and substitution. The overall revision rate was 3.8% with a mean follow-up of 4.1 years, with 42% due to aseptic loosening, 29% due to mechanical failure, and 21% due to infection [14].

Robertsson et al. reported the most recent update from 1988 to 1997 of the Swedish Knee Arthroplasty Register, indicating that the cumulative revision rate for total knee arthroplasty has dropped since 1976, but continues overall to approximately 1% per year of implantation. The average age for the overall group was 71, with 67% being women. By diagnosis, for osteoarthritis the age was 72, while in rheumatoids it was 66. Younger rheumatoid patients had results comparable to older osteoarthritic patients. Implant loosening accounted for 44% of revisions, sepsis 9.9%, and chronic instability 5.7% overall. Fixation of the femoral or patella components was not different with cemented or cementless fixation. The tibia prosthesis had a 1.4 times higher risk of revision if inserted without the use of cement. Revision of the painful patella that was unresurfaced was roughly balanced by fixation failure of the resurfaced patella [44].

Rand and Ilstrup evaluated the cumulative rates of survival in 9,200 operations performed at the Mayo clinic between 1971 and 1987 from a collection of nine different implant types, including revision devices. They found that in patients with primary total knee arthroplasty, a diagnosis of rheumatoid arthritis, an age over 60 years or more, and the use of a condylar prosthesis with a metal-backed tibial component, the probability of an implant remaining in situ was 97% at ten years' follow-up. This, however, was compared with an overall cumulative survivorship of 81% at ten years with all primary knee arthroplasties [41].

The large cohort of patients in our study is unique to the extent that all implants were of similar geometry and inserted with a uniform tibia-cut-first surgical technique by all participating surgeons. The overall average patient age was 68, with 67% of patients being female, 77% having osteoarthritis, and 19% having rheumatoid arthritis. Fixation was cementless in 69% of femurs and tibias, with 77% of resurfaced patellae being cementless. The distribution of implants in this study was 47.5% RP, 45.6% PCR, and 6.8% BCR. In the device groups, there were significantly more patients with rheumatoid arthritis in the BCR group, and significantly more males with the RP prosthesis than females.

The overall revision rate of 5.4% at an average follow-up of 5.7 years closely approximates the 1% per year revision rate reported by other authors. With regard to the various subgroups of this study, there was a slight advantage of cemented fixation over cementless fixation at the longest follow-up. Compared with the rotating platform group, the PCR meniscal bearing group had a 1.5 times higher failure rate, and the BCR meniscal bearing group had a 2.2 times higher failure rate. This study and others have shown a higher bearing failure rate with the meniscal bearings of the latter two groups after ten years' follow-up compared with the more durable rotating platform inserts [11, 12, 29, 54].

From a review of the literature, age, gender, and disease leading to surgery can affect the rates and types of failure following total knee arthroplasty. In general, rates of revision tend to fall with advancing age. As noted by Robertsson et al., this may result from reduced physical activity with less strain on the implant and the greater reluctance to revise elderly patients [44]. Rand and Ilstrup clearly demonstrated lower revision rates for rheumatoid arthritis after primary arthroplasty compared with osteoarthritis and post-traumatic arthritis [41]. Furthermore, females clearly had a lower revision rate overall and in the rheumatoid group [41, 44].

In this study, the osteoarthritic and post-traumatic groups had a 1.8 times higher chance of failure compared with rheumatoids and the "other" group. There was a trend for rheumatoids to have longer survivorship over osteoarthritics in the posterior cruciate retaining group, but in the other implant groups, the outcomes were similar. When comparing osteoarthritics, survivorship was significantly better in the rotating platform group compared with the PCR or BCR groups. Age was significant as the rate of failure decreased by 2.1% for each increased year of age at the time of primary arthroplasty. We found gender to be significant to the extent that overall, females were 1.5 times more likely to experience failure than males. With regard to implant groups, failure in females was clearly greater in all three groups. Regarding the overall incidence for these groups, failure was twice as high with rotating platform and over four times as high for both the bicruciate and the meniscal bearings for females. We have no explanation for this finding.

From the literature, the incidence of bearing failure with the LCS meniscal bearing ranges from 2.5 to 3%, while that of the rotating platform is less than 1% [11–13, 29, 54]. Chronic ligamentous instability resulting from inadequate gap balancing and poor surgical technique could be implicated as the most significant causes of these problems [9, 54]. In this, we combined the incidence of all problems related to bearing failure including instability, bearing dislocation, and bearing wear, as we believe the aetiological factors to be related. This accounted for revision in 3.9% of PCR, 2.4% of BCR, and 0.8% of the RP implants. Furthermore, 42.8% of revisions were caused by bearing failure, while 23.5% were related to mechanical loosening and 7.7% to sepsis. The overall rate of sepsis in this report was quite low at 0.4%, which is comparable with current literature standards. We cannot make further statements regarding measures or controls to eliminate infection, but can state that all reporting surgeons were experienced, high-volume surgeons with noted expertise in the field of total knee arthroplasty. The bicruciate group had a higher than expected rate of infection at 1.2%, which may be attributed to the higher incidence of difficult immunocompromised rheumatoid patients treated at certain centres. Over the course of this study, there has been a substantial shift in surgical technique with the vast majority of centres choosing the meniscal bearing option in 1980s, while those in the 1990s chose the rotating platform approach. The statistical methods remove the bias of surgeon choice, but evolving experience demonstrated the lower failure rates of the rotating platform implants, leading surgeons to switch to this method.

Polyethylene wear–related osteolysis is another failure mechanism leading to revision in certain problematic designs, with 16–30% incidence in some series [20, 21, 23, 37, 57, 59, 61]. An original design parameter of the LCS was optimising the amount of polyethylene contact stress by increasing prosthetic congruity and area contact of the device. An initial concern was the potential for backside wear of the dual articulating surface of the mobile prosthesis, although the LCS design used a hard, polished chromium-cobalt tibial tray, which attempted to minimise this wear. Retrievals of the LCS have not revealed significant backside wear, nor has there been articulation wear on the rotating platform peg or the meniscal bearing runners [16]. Conversely, some authors have reported concern about backside wear of modular fixed-bearing tibial components due to motion between the metal modular tibial tray and the polyethylene insert [21, 37, 57]. The occurrence of catastrophic periprosthetic osteolysis as a failure mechanism was extremely low in this multi-centre study, as it was noted in only two cases. However, it must be presumed that most patients with implant loosening in this study had chronic osteolysis as an important mechanism of failure. Lacking a radiographic review, we cannot posit the actual presence of osteolysis as a failure mechanism. Other reports evaluating the LCS prosthesis that have included radiographic analysis have rarely encountered osteolysis [8, 12, 29, 30, 54]. Nonetheless, it has been noted to have occurred [47].

Patellofemoral failures have been noted in other investigations [3, 24, 28, 32, 33, 46]. These failures have been associated with poorly designed metal-backed components, patellar complications such as fracture or subluxation, and more subtle problems such as patellar “clunk.” Several reports have indicated a high incidence of problems, ranging from four to 21% of cases [20, 21, 23, 37, 57, 59]. While the original designers reported excellent long-term results with the LCS mobile bearing patella, a number of other independent studies have shown similar experience with the rotating patella [10, 29, 30, 54]. In this study the results of patellar resurfacing were good, with an overall complication rate of 0.5% and a 15-year survivorship of 98.5%. We attribute this to a variety of factors including the favourable anatomical shape of the femoral component with a deepened intercondylar sulcus, the tibia-cut-first technique, which optimises femoral component external rotation, and the highly conforming mobile patellar implant that maximises the area of contact through an arc of motion. Patellar non-resurfacing was done in later years, and has become the standard in several European centres. Although only a few cases have required secondary patella resurfacing, we are unable to project the long-term efficacy of this method.

In conclusion, this study is a large multi-centre survivorship analysis of the LCS mobile bearing total knee replacement, with technique and implants that have remained constant during the period of study. Patients at higher risk of failure are younger, female, osteoarthritic, and post-traumatic, who have undergone mobile meniscal bearing replacement. The most durable approach was the cemented, posterior cruciate sacrificing, rotating platform, device compared with other options. Reoperation for patellar problems was extremely low when compared with the general total knee experience and can be cited as favourable for the LCS implant. These advantages must be balanced against the persistent problems of bearing dislocation and bearing failure, which constituted the most significant causes of revision over other issues such as sepsis and implant loosening.

References

1. Argenson J-N, O’Connor JJ (1992) Polyethylene wear in meniscal knee replacement. A one to nine-year retrieval analysis of the Oxford knee. J Bone Joint Surg 74-B:228–232
2. Bartel DL, Bicknell VL, Wright TM (1986) The effect of conformity, thickness, and material on stresses in ultra-high molecular weight components for total joint replacement. J Bone Joint Surg 68-A:1041–1051
3. Bayley JC, Scott RD, Ewald FC, Holmes GB (1988) Failure of the metal-backed patellar component after total knee replacement. J Bone Joint Surg 70A:668–674
4. Becker MW, Insall JN, Faris PM (1991) Bilateral total knee arthropalsty. One cruciate retaining and once cruciate substituting. Clin Orthop 271:122–124
5. Berger RA, Rosenberg AG, Barden RM, Sheinkop MB, Jacobs JJ, Galante JO (2001) Long-term followup of the Miller-Galante total knee replacement. Clin Orthop 388:58–67
6. Bert JM (1990) Dislocation/subluxation of meniscal bearing elements after New Jersey low-contact stress total knee arthroplasty. Clin Orthop 254:211–215
7. Buechel FF, Pappas MJ (1986) The New Jersey low-contact-stress knee replacement system: biomechanical rationale and review of the first 123 cemented cases. Arch Orthop Trauma Surg 105:197–204
8. Buechel FF, Pappas MJ (1989) New Jersey low contact stress knee replacement system. Ten-year evaluation of meniscal bearings. Orthop Clin North Am 20:147–177
9. Buechel FF, Pappas MJ (1990) Long-term survivorship analysis of cruciate-sparing versus cruciate-sacrificing knee prostheses using meniscal bearings. Clin Orthop 260:162–169
10. Buechel FF, Rosa RA, Pappas MJ (1989) A metal-backed, rotating-bearing patellar prosthesis to lower contact stress. An 11-year clinical study. Clin Orthop 248:34–49
11. Buechel FF Sr, Buechel FF Jr, Pappas MJ, D’Alessio J (2000) Twenty-year evaluation of meniscal bearing and rotating platform knee replacements. Clin Orthop 388:41–50
12. Buechel Sr FF, Buechel Jr FF, Pappas MJ, D’Alessio J (2002) Twenty-year evaluation of the New Jersey LCS rotating platform knee replacement. J Knee Surg 15:84–89
13. Callaghan JJ, Squire MW, Goetz DD et al (2000) Cemented rotating-platform total knee replacement. J Bone Joint Surg 82A:705–711
14. Callahan CM, Drake BG, Heck DA, Dittus RS (1994) Patient outcomes following tricompartmental total knee replacement. A meta-analysis. J Am Med Assoc 271:1349–1357
15. Colizza WA, Insall JA, Scuderi GR (1995) The posterior stabilized total knee prosthesis. Assessment of polyethylene damage and osteolysis after a ten-year-minimum follow-up. J Bone Joint Surg 77-A:1713–1720
16. Collier JP, Mayor MB, McNamara JL, Surprenant VA, Jensen RE (1991) Analysis of the failure of 122 polyethylene inserts from uncemented tibial knee components. Clin Orthop 273:232–242
17. Dennis DA, Clayton ML, O’Donnell S, Mack RP, Stringer EA (1999) Posterior cruciate condylar total knee arthroplasty. Average 11-year follow-up evaluation. Clin Orthop 281: 168–176
18. Dorey F, Amstutz HC (1986) Survivorship analysis in total joint arthroplasty. J Arthroplasty 1:63–69
19. Dorr LD, Ochsner JL, Gronley J, Perry J (1988) Functional comparison of posterior cruciate-retained versus cruciate-sacrificed total knee arthroplasty. Clin Orthop 236:36–43
20. Engh GA (1988) Failure of the polyethylene bearing surface of a total knee replacement within four years. A case report. J Bone Joint Surg 70-A:1093–1096
21. Engh GA, Dwyer, KA, Hanes CK (1992) Polyethylene wear of metal-backed tibial components in total and unicompartmental knee prostheses. J Bone Joint Surg 74-B:9–17
22. Ewald FC, Wright RJ, Poss R, Thomas WH, Mason MD, Sledge CB (1999) Kinematic total knee arthroplasty: a 10- to 14-year prospective follow-up- review. J Arthroplasty 14: 473–480
23. Ezzet KA, Garcia R, Barrack RL (1995) Effect of component fixation method on osteolysis in total knee arthroplasty. Clin Orthop 321:86–91
24. Figgie HE III, Goldberg VM, Inglis AE, Kelly M, Sobel M (1989) The effect of alignment of the implant on fractures of the patella after condylar total knee arthroplasty. J Bone Joint Surg 71A:1031–1039
25. Font-Rodriguez DE, Scuderi GR, Insall JN (1997) Survivorship of cemented total knee arthroplasty. Clin Orthop 345:79–86
26. Goodfellow J, O’Connor JJ (1978) The mechanics of the knee and prosthesis design. J Bone and Joint Surg 60-B:358–362
27. Goodfellow JW, O’Connor JJ (1986) Clinical results of the Oxford knee. Surface arthroplasty of the tibiofemoral joint with a meniscal bearing prosthesis. Clin Orthop 205:21–42
28. Insall JN, Ranawat CS, Aglietti P, Shine J (1976) A comparison of four models of total knee-replacement prostheses. J Bone Joint Surg 58-A:754–765

29. Jordan LR, Olivo JL, Voorhorst PE (1997) Survivorship analysis of cementless meniscal bearing total knee arthroplasty. Clin Orthop Relat Res 338:119–123
30. Keblish PA, Varma AK, Greenwald AS (1994) Patellar resurfacing or retention in total knee arthroplasty. A prospective study of patients with bilateral replacements. J Bone Joint Surg 76B:930–937
31. Laskin RS (2001) The Genesis total knee prosthesis. Clin Orthop 388:95–102
32. Lombardi AV, Engh GA, Volz RG, Albrigo JL, Brainard BJ (1988) Fracture/dislocation of the polyethylene in metal-backed patellar components in total knee arthroplasty. J Bone Joint Surg 70A:675–679
33. MacCollum MS, Karpman RR (1989) Complications of the PCA anatomic patella. Orthopaedics 12:1423–1428
34. McNamara JL, Collier JP, Mayor MB, Jensen RE (1994) A comparison of contact pressures in tibial and patellar total knee components before and after service in vivo. Clin Orthop 299:104–113
35. Malkani AL, Rand JA, Bryan RS, Wallrichs SL (1995) Total knee arthroplasty with the kinematics condylar prosthesis. A ten-year follow-up study. J Bone Joint Surg 77-A:423–431
36. O'Connor JJ, Goodfellow JW (1996) Theory and practice of meniscal knee replacement: designing against wear. Proc Inst Mech Eng [H] 210:217–222
37. Parks NL, Engh GA, Topoleski LD, Emperado J (1998) Modular tibial insert micromotion. A concern with contemporary knee implants. Clin Orthop 356:10–15
38. Pavone V, Boettner F, Fickert S, Sculco TP (2001) Total condylar arthroplasty. A long-term follow-up. Clin Orthop 388:18–25
39. Ranawat CS, Boachie-Adjei O (1988) Survivorship analysis and results of total condylar knee arthroplasty. Eight- to 11-year follow-up period. Clin Orthop 226:6–13
40. Ranawat CS, Flynn WF Jr, Deshmukh RG (1994) Impact of modern technique on long-term results of total condylar knee arthroplasty. Clin Orthop 309:131–135
41. Rand JA, Ilstrup DM (1991) Survivorship analysis of total knee arthroplasty. Cumulative rates of survival of 9200 total knee arthroplasties. J Bone Joint Surg 73-A:397–409
42. Ritter MA, Campbell E, Faris PM, Keating EM (1989) Long-term survival analysis of the posterior cruciate condylar total knee arthroplasty. A 10-year evaluation. J Arthroplasty 4:293–296
43. Ritter MA, Berend ME, Meding JB, Keating EM, Faris PM, Crites BM (2001) Long-term followup of anatomic graduated components posterior cruciate-retaining total knee replacement. Clin Orthop 388:51–57
44. Robertsson O, Knutson K, Lewold S, Lidgren L (2001) The Swedish knee arthroplasty register 1975-1997: an update with special emphasis on 41223 knees operated on in 1988–1997. Acta Orthop Scand 72:503–513
45. Rodriguez JA, Bhende H, Ranawat CS (2001) Total condylar replacement. A 20-year followup study. Clin Orthop 388:10–17
46. Rosenberg AG, Andriacchi TP, Barden R, Galante JO (1988) Patellar component failure in cementless total knee arthroplasty. Clin Orthop 236:106–114
47. Sánchez-Sotelo J, Ordonez JM, Prats SB (1999) Results and complications of the low contact stress knee prosthesis. J Arthroplasty 14:815–821
48. Schai PA, Thornhill TS, Scott RD (1998) Total knee arthroplasty with the PFC system. Results at a minimum of ten years and survivorship analysis. J Bone Joint Surg 80-B:850–858
49. Scott RD, Volatile TB (1986) Twelve years' experience with posterior cruciate-retaining total knee arthroplasty. Clin Orthop 205:100–107
50. Scott WN, Rubinstein M, Scuderi G (1988) Results after knee replacement with a posterior cruciate-substituting prosthesis. J Bone Joint Surg 70-A:1163–1173
51. Scuderi GR, Insall JN, Windsor RE, Moran MC (1989) Survivorship of cemented knee replacements. J Bone Joint Surg 71-B:798–804
52. Sextro GS, Berry DJ, Rand JA (2001) Total knee arthroplasty using cruciate-retaining kinematic condylar prosthesis. Clin Orthop 388:33–40
53. Shoji H, Wolf A, Packard S, Yoshino S (1994) Cruciate retained and excised total knee arthroplasty. A coparative study in patients with bilateral total knee arthroplasty. Clin Orthop 205:218–222
54. Sorrells RB (1996) Primary knee arthroplasty: long-term outcomes. The rotating platform mobile bearing TKA. Orthopedics 19:793–796
55. Stern SH, Insall JN (1992) Posterior stabilized prosthesis. Results after follow-up of nine to twelve years. J Bone Joint Surg 74-A:980–986
56. Vince KG, Insall JN, Kelly MA (1989) The total condylar prosthesis. 10- to 12-year results of a cemented knee replacement. J Bone Joint Surg 71-B:793–797
57. Wasielewski RC, Parks N, Williams I, Surprenant H, Collier JP, Engh G (1997) Tibial insert undersurface as a contributing source of polyethylene wear debris. Clin Orthop 345:53–59
58. Weaver JK, Derkash RS, Greenwald SD (1993) Difficulties with bearing dislocation and breakage using a movable bearing total knee replacement system. Clin Orthop 290:244–252
59. Whiteside LA (1995) Effect of porous-coating configuration on tibial osteolysis after total knee arthroplasty. Clin Orthop 321:92–97
60. Whiteside LA (2001) Long-term followup of the bone-ingrowth Ortholoc knee system without a metal-backed patella. Clin Orthop 388:77–84
61. Wright TM, Bartel DL (1986) The problem of surface damage in polyethylene total knee components. Clin Orthop 205:67–74