International Comparative Evaluation of Fixed-Bearing Non-Posterior-Stabilized and Posterior-Stabilized Total Knee Replacements

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Background: Differences in survivorship of non-posterior-stabilized compared with posterior-stabilized knee designs carry substantial economic consequences, especially with limited health-care resources. However, these comparisons have often been made between relatively small groups of patients, often with short-term follow-up, with only small differences demonstrated between the groups. The goal of this study is to compare the outcomes of non-posterior-stabilized and posterior-stabilized total knee arthroplasties with use of a unique collaboration of multiple established knee arthroplasty registries.

Methods: A distributed health data network was developed by the International Consortium of Orthopaedic Registries and was used in this study to reduce barriers to participation (such as security, propriety, legal, and privacy issues) compared with a centralized data warehouse approach. The study included only replacements in osteoarthritis patients who underwent total knee procedures involving fixed-bearing devices from 2001 to 2010. The outcome of interest was time to first revision.

Results: On average, not resurfacing showed a more harmful effect than resurfacing did when posterior-stabilized and non-posterior-stabilized knee replacements were compared, while the risk of revision for posterior-stabilized compared with non-posterior-stabilized knees was highest in year zero to one, followed by year one to two, years eight through ten, and years two through eight. Posterior-stabilized knees did significantly worse than non-posterior-stabilized knees did when the patella was not resurfaced. This difference was most pronounced in the first two years (year zero to one: hazard ratio [HR] = 2.15, 95% confidence interval [CI] = 1.56 to 2.95, $p < 0.001$; year one to two: HR = 1.61, 95% CI = 1.48 to 1.75, $p < 0.001$). When the patella was resurfaced, posterior-stabilized knees did significantly worse than non-posterior-stabilized knees did. This was again most pronounced in the first two years (year zero to one: HR = 1.75, 95% CI = 1.27 to 2.42, $p = 0.001$; year one to two: HR = 1.31, 95% CI = 1.19 to 1.45, $p < 0.001$). There was a reduced risk of revision with a patient age of more than sixty-five years (HR = 0.57, 95% CI = 0.55 to 0.60, $p < 0.001$).

Conclusions: We found that fixed non-posterior-stabilized total knee arthroplasty performed better with or without patellar resurfacing than did fixed posterior-stabilized total knee arthroplasty. This effect was most pronounced in the first two years. The risk of revision for posterior-stabilized total knee arthroplasties was reduced with patellar resurfacing. Also, a patient age of more than sixty-five years and female gender reduced the risk of revision.

The growth in demand for total knee arthroplasties and the increased cost burden of these primary and revision procedures[1] have placed a premium on the optimization of outcomes. Differences in survivorship of non-posterior-stabilized (posterior cruciate-retaining) compared with posterior-stabilized (posterior cruciate-substituting) knee designs carry substantial economic consequences, especially with limited health-care resources.

The ongoing debate regarding the choice of non-posterior-stabilized or posterior-stabilized techniques has been addressed on

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TABLE I Distribution of Knee Implants by Registry, Stability, Age, Sex, and Resurfacing Status*

	U.S. (KP)	Australia	Italy (E-R)	Sweden	Norway	Spain (C)
Fixed-bearing non-posterior-stabilized						
Age in yr						
<45	102 (0.7)	671 (0.5)	13 (0.2)	247 (0.3)	58 (0.4)	4 (0)
45 to 55	1343 (9.0)	9319 (6.9)	119 (2.1)	3980 (5.1)	670 (4.6)	56 (0.5)
56 to 65	4634 (30.9)	34,801 (25.9)	786 (13.9)	19,242 (24.5)	3430 (23.8)	719 (6.8)
>65	8904 (59.4)	89,369 (66.6)	4731 (83.7)	54,976 (70.1)	10,258 (71.2)	9758 (92.6)
Sex						
Male	5573 (37.2)	57,330 (42.7)	1464 (25.9)	31,357 (40.0)	4657 (32.3)	2885 (27.4)
Female	9410 (62.8)	76,830 (57.3)	4185 (74.1)	47,088 (60.0)	9759 (67.7)	7652 (72.6)
Fixation						
Cementless	627 (4.2)	32,401 (24.2)	619 (11.0)	1042 (1.3)	385 (2.7)	594 (5.6)
Hybrid	1828 (12.2)	40,572 (30.2)	278 (4.9)	49 (0.1)	1926 (13.4)	3511 (33.3)
Cemented	12,528 (83.6)	61,187 (45.6)	4752 (84.1)	77,354 (98.6)	12,105 (84.0)	6432 (61.0)
Resurfacing						
No	608 (4.1)	78,553 (58.6)	5457 (96.6)	73,639 (93.9)	13,785 (95.6)	7536 (71.5)
Yes	14,375 (95.9)	55,607 (41.4)	192 (3.4)	4806 (6.1)	631 (4.4)	3001 (28.5)
Fixed-bearing posterior-stabilized						
Age in yr						
<45	203 (0.6)	281 (0.5)	13 (0.2)	13 (0.2)	7 (0.9)	4 (0)
45 to 55	3047 (8.4)	3631 (6.9)	136 (1.6)	333 (6.3)	45 (5.8)	69 (0.7)
56 to 65	10,768 (29.8)	14,354 (27.4)	1161 (13.8)	1282 (24.2)	169 (21.8)	835 (8.1)
>65	22,149 (61.2)	34,141 (65.1)	7095 (84.4)	3664 (69.2)	553 (71.4)	9384 (91.2)
Sex						
Male	13,327 (36.8)	22,228 (42.4)	2148 (25.6)	1973 (37.3)	201 (26.0)	2969 (28.8)
Female	22,840 (63.2)	30,179 (57.6)	6257 (74.4)	3319 (62.7)	573 (74.0)	7323 (71.2)
Fixation						
Cementless	926 (2.6)	2970 (5.7)	132 (1.6)	25 (0.5)	15 (1.9)	222 (2.2)
Hybrid	774 (2.1)	2960 (5.6)	64 (0.8)	3 (0.1)	266 (34.4)	1253 (12.2)
Cemented	34,467 (95.3)	46,477 (88.7)	8209 (97.7)	5264 (99.5)	493 (63.7)	8817 (85.7)
Resurfacing						
No	218 (0.6)	21,357 (40.8)	6246 (74.3)	3310 (62.5)	746 (96.4)	5184 (50.4)
Yes	35,949 (99.4)	31,050 (59.2)	2159 (25.7)	1982 (37.5)	28 (3.6)	5108 (49.6)

*The values are given as the number of each, with the percentage in parentheses. KP = Kaiser Permanente, E-R = Emilia-Romagna region, and C = Catalan region.

several fronts. These analyses have explored the differences in the kinematics, patient outcomes, and survival of the implants[2-5]. However, these comparisons have often been made between relatively small groups of patients, often with short-term follow-up, with only small differences demonstrated between the groups[6-8].

Proponents of non-posterior-stabilized designs have claimed that retention of the posterior cruciate ligament provides superior mechanics, controlled femoral roll-back, and reduced stress at the bone-cement interface[9,10]. Supporters of posterior-stabilized designs have claimed that sacrificing the posterior cruciate ligament aids ligament balancing, improves the ability to address substantial angular deformities, and improves knee kinematics[11,12].

The goal of this study is to compare outcomes of non-posterior-stabilized and posterior-stabilized total knee arthroplasties with use of a unique collaboration of multiple established knee arthroplasty registries.

Materials and Methods

A distributed health data network was developed by the International Consortium of Orthopaedic Registries (ICOR) and was used in this study to reduce barriers to participation (such as security, proprietary, legal, and privacy

TABLE II Results from the Fixed-Effects Model*

	Hazard Ratio (95% CI)	P Value
Posterior-stabilized, relative to non-posterior-stabilized		
Nonresurfaced patella		
Year 0 to 1	2.145 (1.562-2.946)	<0.001
Year 1 to 2	1.610 (1.478-1.753)	<0.001
Years 2 through 8	1.425 (1.326-1.531)	<0.001
Years 8 through 10	1.497 (1.364-1.643)	<0.001
Resurfaced patella		
Year 0 to 1	1.751 (1.269-2.415)	0.001
Year 1 to 2	1.314 (1.187-1.454)	<0.001
Years 2 through 8	1.163 (1.061-1.274)	0.001
Years 8 through 10	1.222 (1.096-1.362)	<0.001
Sex by resurfacing status		
Male, no resurfacing	Ref.	
Female, no resurfacing	1.008 (0.955-1.064)	0.765
Male, resurfacing	0.944 (0.861-1.036)	0.227
Female, resurfacing	0.658 (0.601-0.720)	<0.001
Fixation by resurfacing status		
Cemented, no resurfacing	Ref.	
Hybrid, no resurfacing	0.885 (0.812-0.964)	0.005
Cemented, resurfacing	0.944 (0.861-1.036)	0.227
Hybrid, resurfacing	1.017 (0.902-1.147)	0.778
Age in yr		
≤65	Ref.	
>65	0.570 (0.546-0.595)	<0.001
Fixation		
Cemented	Ref.	
Cementless	1.040 (0.951-1.138)	0.389

*Results are based on an iterative solution that updates the residual covariances until convergence. Fixed registry effects were included in this model. Confidence intervals and p values are based on t_{n-p}.

issues) compared with a centralized data warehouse approach[13,14]. A distributed health data network is a decentralized model that allows secure storage and analysis of data from various registries[15]. In general terms, the data from each registry are standardized and given at the level of aggregation most suitable for the detailed analysis of interest, with the aggregated data combined across registries[16].

The first step in developing the health data network was to evaluate the international variation in practice patterns, including patient selection, technology use, and procedural detail. All interested registries participated, and a methodology committee discussed inclusion of key variables for analytic purposes. Next, each registry with an interest in participating completed simple tables depicting the means and proportions of patient and procedure-related characteristics. Six national and regional registries (those of Kaiser Permanente [U.S.], Sweden, the Emilia-Romagna region of Italy, the Catalan region of Spain, Norway, and Australia) were involved in this study.

Our primary interest was the comparison of two categories of total knee arthroplasty designs: fixed-bearing non-posterior-stabilized and fixed-bearing posterior-stabilized. We were also interested in the possibility of time-dependent effects for this comparison as well as possible interactive effects with other variables. A secondary objective of ours was to identify risk factors for revision beyond the stability comparison. Given that fixed-bearing prostheses are the most frequently used knee implants, the effects of patient age, sex, resurfacing status, and fixation method are of interest in and of themselves, apart from their possible role as confounders for the stability group comparison. The study included only replacements in osteoarthritis patients who underwent total knee procedures involving fixed-bearing devices from 2001 to 2010; it excluded replacements involving constrained and hinged devices as well as reverse hybrid procedures. The outcome of interest was time to first revision, which was defined as the removal, exchange, or addition of any implant part; this included patellar replacement and an exchange of inserts with or without patellar replacement. The sample sizes by registry, stability, age, sex, and resurfacing status are presented in Table I.

Statistical Analyses

Multivariate meta-analysis was performed with use of linear mixed models, with survival probability as the unit of analysis[17]. The models estimated the residual covariance with the exact method reported previously[18] and also implemented a transformation[19-21] to ensure that the models could be fitted with use of existing SAS software (version 9.2; SAS Institute, Cary, North Carolina). Survival probabilities and their standard errors were extracted from each registry for each unique combination of the covariates (e.g., patient age) at each distinct event time. Each unique combination of covariates was grouped into yearly time intervals, with only the earliest observation in that interval retained. We fitted two models, one that treated the registries as a set of fixed effects and another that treated them as random effects.

TABLE III Results from the Random-Effects Model*

	HR (95% CI)	P Value
Posterior-stabilized, relative to non-posterior-stabilized		
Nonresurfaced patella		
Year 0 to 1	1.909 (1.120-3.254)	0.026
Year 1 to 2	1.396 (0.977-1.994)	0.061
Years 2 through 8	1.236 (0.869-1.757)	0.183
Years 8 through 10	1.295 (0.903-1.857)	0.124
Resurfaced patella		
Year 0 to 1	1.534 (0.896-2.627)	0.096
Year 1 to 2	1.122 (0.780-1.615)	0.453
Years 2 through 8	0.993 (0.693-1.423)	0.963
Years 8 through 10	1.041 (0.721-1.503)	0.790
Sex by resurfacing status		
Male, no resurfacing	Ref.	
Female, no resurfacing	1.005 (0.952-1.060)	0.867
Male, resurfacing	0.940 (0.853-1.035)	0.209
Female, resurfacing	0.660 (0.601-0.725)	<0.001
Fixation by resurfacing status		
Cemented, no resurfacing	Ref.	
Hybrid, no resurfacing	0.910 (0.834-0.993)	0.034
Cemented, resurfacing	0.940 (0.853-1.035)	0.209
Hybrid, resurfacing	1.037 (0.919-1.170)	0.555
Age in yr		
≤65	Ref.	
>65	0.570 (0.546-0.595)	<0.001
Fixation		
Cemented	Ref.	
Cementless	1.077 (0.983-1.180)	0.112

*Results are based on an iterative solution that updates the residual covariances until convergence. The random-effects model is estimated with restricted maximum likelihood. Our simulations indicated that an optimal strategy for confidence-interval construction in the presence of random effects is to use $t_{\kappa-1}$ for fixed parameters with corresponding random effects and t_{n-p} otherwise. In this table, most of the reported effects are linear combinations of the parameter estimates, with those involving a comparison of posterior-stabilized and non-posterior-stabilized knee replacements having varying degrees of freedom. For a conservative measure we used $t_{\kappa-1}$ for confidence intervals and p values for these effects as well as t_{n-p} for all other effects in this table.

Although the random-effects model offers some inferential advantage for combining studies[22,23], with few observational data and/or registries, the estimated between-registry variation in the random-effects model can be rather inaccurate. In addition, the absence of randomization for fixed-bearing posterior-stabilized compared with fixed-bearing non-posterior-stabilized groups can lead to confounding because of registry-level effects, which the random-effects model does not address but the fixed-effects model does[24,25]. Therefore, we gave preference to interpretation of the fixed-effects model, particularly if the parameter estimates were substantially different in the fixed-effects compared with the random-effects model[24,25].

We present the results of the fixed-effects model in Table II and include the results of the random-effects model in the Appendix. SAS version 9.2 was used for all analyses.

Results

This study included 371,527 knee implants; 61% (225,415) of these were in female patients. Five-year revision rates varied across registries, from 1.8% to 3.5%. Distribution of the implants by registry, stability, age, sex, and resurfacing status is given in Table I.

For the fixed-effects model, we included terms for an intercept, stability, age, sex, fixation method, resurfacing status, piecewise constant function of time, the interaction of stability and time, the interaction of stability (main effect) and resurfacing, the interaction of sex and resurfacing, the interaction of fixation and resurfacing, and residual variance fixed at one. Additional details regarding the model fitting are given in the Appendix. Given the large number of interaction terms in this model, model parameter estimates expressed as hazard ratios are not shown; rather, combinations of parameter estimates expressed as hazard ratios are shown (Tables II and III). We saw notable differences between the estimates from the random and

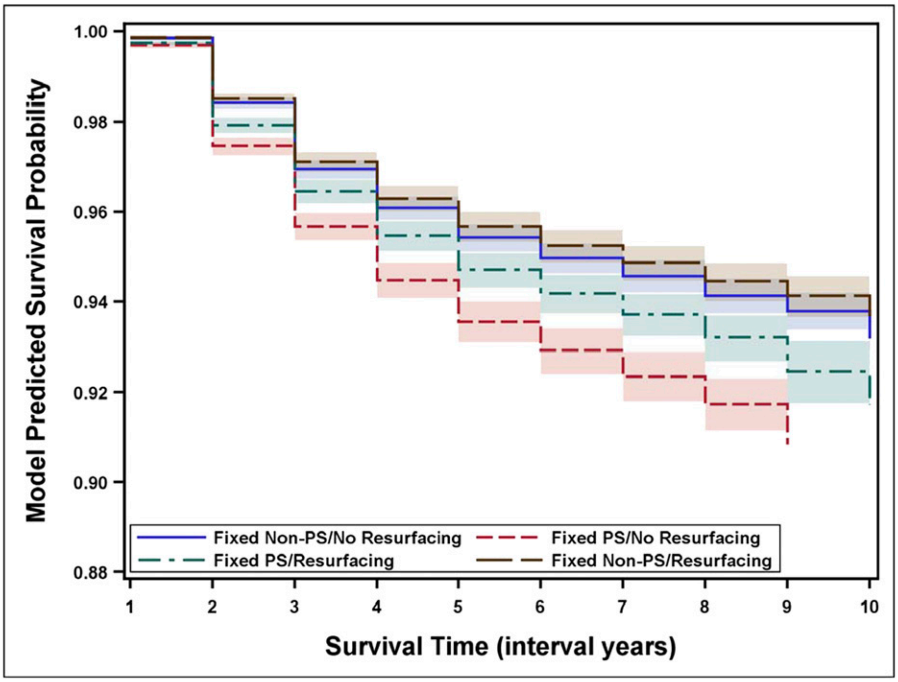

Fig. 1

Model-predicted implant survival by stability and resurfacing status. The shading indicates the 95% confidence interval. PS = posterior-stabilized.

fixed-effects models, particularly for comparisons of posterior-stabilized and non-posterior-stabilized groups by resurfacing status over time; therefore, we focused on interpretation of the fixed-effects results.

The first group of entries in Table II compares posterior-stabilized and non-posterior-stabilized knee replacements separately by patellar-resurfacing status and time because the effect is modified by these two variables. Regarding patellar-resurfacing status, not resurfacing generally tends to show a more harmful effect than resurfacing does when comparing posterior-stabilized and non-posterior-stabilized knee replacements. With respect to time, the pattern is such that the risk of revision for posterior-stabilized compared with non-posterior-stabilized knee replacements is highest in year zero to one, followed by year one to two, years eight through ten, and years two through eight. In all years, we saw posterior-stabilized knee replacements doing significantly worse than non-posterior-stabilized knee replacements did when the patella was not resurfaced, but this difference was most pronounced in the first two years (year zero to one: hazard ratio [HR] = 2.15, 95% confidence interval [CI] = 1.56 to 2.95, $p < 0.001$; year one to two: HR = 1.61, 95% CI = 1.48 to 1.75, $p < 0.001$). When the patella was resurfaced, in all years we saw posterior-stabilized knee replacements doing significantly worse than non-posterior-stabilized knee replacements did; again, this difference was most pronounced in the first two years (year zero to one: HR = 1.75, 95% CI = 1.27 to 2.42, $p = 0.001$; year one to two: HR = 1.31, 95% CI = 1.19 to 1.45, $p < 0.001$). Survival probabilities (estimated from the fixed-effects model) by stability and resurfacing status are shown in Figure 1.

There were additional effects in the model that are noteworthy because they are able to further characterize the risk of revision. Among these were a reduced risk of revision with a patient age of more than sixty-five years (HR = 0.57, 95% CI = 0.55 to 0.60, $p < 0.001$). There was also a strong interactive effect of sex and patellar resurfacing, such that female patients who had patellar resurfacing were at significantly reduced risk of revision compared with male patients who had no patellar resurfacing (HR = 0.66, 95% CI, 0.60 to 0.72, $p < 0.001$). Lastly, among individual patients who did not have patellar resurfacing, hybrid fixation of the implant led to a reduced risk of revision compared with cemented fixation of the implant (HR = 0.89, 95% CI = 0.81 to 0.96, $p = 0.005$).

Discussion

Previous studies comparing outcomes between non-posterior-stabilized and posterior-stabilized total knee arthroplasty have failed to show significant differences[7,8]. Prior reports have often included small sample sizes, retrospective data, or short-term follow-up. The current analysis involved six national and regional registries and had a study population of 371,527 fixed-bearing devices. There was significantly improved survivorship of non-posterior-stabilized compared with posterior-stabilized devices at all time intervals, especially in the first two years. Our findings support and substantially advance the evidence reported by some researchers[11]. We acknowledge that patient selection might be a confounder, since posterior-stabilized devices have been recommended for knees with greater deformities. Therefore, knee deformity may confound the relationship between the treatment and the revision risk. However, the extent of confounding depends on the degree of the selection bias and the difference in risk of revision associated with increased knee deformity. Kubiak et al. reported good results in their study of non-posterior-stabilized total knee arthroplasty performed in patients with ≥15° of coronal plane deformity compared with an historical control of posterior-stabilized knee replacements. They reported 93% survival of non-posterior-stabilized total knee replacement in this subset of patients at minimum ten-year follow-up[26]. Abdel et al. reported that at fifteen years the non-posterior-stabilized knee replacements performed slightly better in the knees with deformities than in those without deformities and that the opposite was true for posterior-stabilized knee replacements, which performed better in the knees without deformities[11].

The role of patellar resurfacing in total knee arthroplasty has been investigated, often with contradictory results[27-32]. The results of our study indicate that the revision risk for posterior-stabilized knees is double that for non-posterior-stabilized knees in cases with nonresurfaced patellas. Johnson et al.[33] found higher rates of revision for total knee arthroplasty performed without patellar resurfacing. In their community joint registry study, the cumulative revision rate for total knee arthroplasties with nonresurfaced patellas was 8.2% compared with 6.3% for resurfaced patellar cases at eighteen years. The rate of patella-only revision was also significantly higher: 4.8% compared with 0.8% at eighteen years. The authors were not able to demonstrate a significant difference in cumulative revision rates between non-posterior-stabilized and posterior-stabilized knee replacements with or without patellar resurfacing[33]. Clements et al., using what is believed to be the largest knee arthroplasty registry to date, including 134,799 arthroplasties, demonstrated a 1.33-times greater risk of revision for arthroplasties with no patellar resurfacing compared with resurfaced total knee arthroplasties[34]. The reasons for the increased rate of revision with nonresurfaced patellas are not clear. Evidence has been presented to support mechanical reasons for these failures. Tanzer et al. studied the biomechanics of the patellofemoral articulation of several types of knee replacements. They noted consistent reduction in the contact surface area along with the occurrence of associated high peak patellar pressures, especially in deep flexion. Also evident was the design-dependent nature of these findings[35]. Higher revisions rates with nonresurfaced patellas as seen in our study have been demonstrated by other authors as well[27,28,35]. Lygre et al. found a higher revision rate in arthroplasties, although the finding was not significant. Isolated patellar revision was most often performed for pain, not mechanical loosening, and these revision rates were design-specific[27]. The rate of patellar revision was substantially lower in the second half of the study period, as newer, “patella-friendly” designs were introduced[27]. The higher failure rate associated with nonresurfaced posterior-stabilized knees compared with non-posterior-stabilized designs in the current study cannot be explained by our data. This outcome was not found in the study by Johnson et al.[33].

Several other findings regarding resurfacing status during total hip arthroplasty involved female patients with patellar resurfacing, including a significantly lower risk of revision compared with male patients who did not undergo patellar resurfacing. For knee replacements that did not involve patellar resurfacing, the use of hybrid fixation reduced the risk of revision compared with knee replacements that had cemented fixation.

The strengths of the study include its size. To our knowledge, it is the largest multinational prospective registry cohort study based on data from six registries. Data acquisition was aided by addressing the issues of confidentiality and privacy of the patients with use of distributed analyses and/or standardized syntax to extract aggregated data from each registry. This approach did not necessitate institutional review board approval.

A potential weakness of our study is the inability to account for some confounding variables, such as the extent of knee deformity. The pooled data are limited to data elements that are common across registries. Unfortunately, this limits the extent to which confounding can be addressed. Evidence from the study by Abdel et al. indicates that this may not be important [11]. Significant differences in the surgical technique have been brought to light through this analysis[27,28,33]. Some registries contained relatively few posterior-stabilized procedures. Significant differences in the rates of patellar resurfacing existed between registries and had a major effect on survival[29-32]. Some registries within the group are larger than others, with different follow-up intervals, and therefore might have had a greater influence on the results.

Conclusions

In what we believe is the largest study of its kind to date, fixed-bearing non-posterior-stabilized total knee arthroplasty performed better both with and without patellar resurfacing than did fixed-bearing posterior-stabilized total knee arthroplasty. This effect was most pronounced in the first two years. The risk of revision for posterior-stabilized total knee replacements was reduced with patellar resurfacing, a patient age of more than sixty-five years, and female sex.

Appendix: Model-Fitting Details

Data Inclusion

For the models described here, we chose to retain observations with a standard error of <0.0125, given that the simulations indicated increased bias, root-mean-squared error, and poorer coverage when observations with large degrees of imprecision (resulting from sparse data for certain covariate combinations) were retained. The 0.0125 threshold was based on both the simulation results and a sensitivity analysis of the effect on model parameters when different levels of restriction (0.05, 0.025, and 0.0125) were applied.

Model Selection

The fixed-effects model was based on the random-effects model selected. For the random-effects model, the interaction terms involving time were based on years: year zero to one up through year nine to ten. According to the results of a likelihood ratio test with maximum likelihood estimation, the stability-by-time interaction terms improved fit (χ^2 [9] = 39.10; $p < 0.001$). We observed a pattern in the estimated time effects, such that the hazard ratio was approximately constant for zero to one, one to two, two through eight, and eight through ten years. Refitting a model with these groupings led to nonsignificant differences from the model with yearly treatment effects estimated (χ^2 [6] = 7.96; p = 0.241). Therefore, we adopted the latter specification. Random effects corresponding to these interaction terms were all estimated to be near zero and were therefore not added to the model. Next, we examined all possible pairwise interactions between sex, age, resurfacing status, and fixation, which indicated an overall effect (χ^2 [9] = 89.40; p < 0.001). However, among these only sex*resurfacing and fixation*resurfacing were significant according to a *Z* test (p < 0.05), and therefore only these were retained.

We explored whether there was evidence for interaction between stability (main effect) and age, resurfacing, fixation, or sex. A global test of these two-way interactions indicated evidence of an effect (χ^2 [5] = 11.63; p < 0.040). Among these interactions, only stability*resurfacing was significant based on a *Z* test (p = 0.009). Therefore, only this term was retained. Retaining only significant coefficients at each step of the model-fitting process is not an ideal strategy for model selection. However, given the large number of candidate models and complex model-fitting process, this was the most feasible approach. Furthermore, we limited variable selection to a specific set of two-way interactions. Certainly, other two-way and higher-order interactions could have been considered. There was substantial between-registry variation in the stability group comparison ($\sigma^2_{stability}$ = 0.95; standard error = 0.068). Examination of the empirical best linear unbiased predictors for the stability group comparison indicated that compared with the average, Italy (Emilia-Romagna region) had the least evidence for the harmful effects of posterior-stabilized knee replacements, followed by Spain (Catalan region), the U.S. (Kaiser Permanente), Norway, Australia, and Sweden: −0.496, −0.102, −0.004, 0.050, 0.255, and 0.297, respectively. ■

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