Impact of patient and prosthesis characteristics on common reasons for total knee replacement revision: a registry study of 36,626 revision cases from Australia, Sweden, and USA

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Background and purpose — Total knee replacement (TKR) studies usually analyze all-cause revision when considering relationships with patient and prosthesis factors. We studied how these factors impact different revision diagnoses.

Patients and methods — We used data from 2003 to 2019 of TKR for osteoarthritis from the arthroplasty registries of Sweden, Australia, and Kaiser Permanente, USA to study patient and prosthesis characteristics for specific revision diagnoses. There were 1,072,924 primary TKR included and 36,626 were revised. Factors studied included age, sex, prosthesis constraint, fixation method, bearing mobility, polyethylene type, and patellar component use. Revision diagnoses were arthrofibrosis, fracture, infection, instability, loosening, pain, patellar reasons, and wear. Odds ratios (ORs) for revision were estimated and summary effects were calculated using a meta-analytic approach.

Results — We found between-registry consistency in 15 factor/reason analyses. Risk factors for revision for arthrofibrosis were age < 65 years (OR 2.0; 95% CI 1.4–2.7) and mobile bearing designs (MB) (OR 1.7; CI 1.1–2.5), for fracture were female sex (OR 3.2; CI 2.2–4.8), age ≥ 65 years (OR 2.8; CI 1.9–4) and posterior stabilized prostheses (PS) (OR 2.1; CI 1.3–3.5), for infection were male sex (OR 1.9; CI 1.7–2.0) and PS (OR 1.5; CI 1.2–1.8), for instability were age < 65 years (OR 1.5; CI 1.3–1.8) and MB (OR 1.5; CI 1.1–2.2), for loosening were PS (OR 1.5; CI 1.4–1.6), MB (OR 2.2; CI 1.6–3.0) and use of ultra-high molecular weight polyethylene (OR 2.3; CI 1.8–2.9), for patellar reasons were not resurfacing the patella (OR 13.6; CI 2.1–87.2) and MB (OR 2.0; CI 1.2–3.3) and for wear was cementless fixation (OR 4.9; CI 4.3–5.5).

Interpretation — Patients could be counselled regarding specific age and sex risks. Use of minimally stabilized, fixed bearing, cemented prostheses, and patellar components is encouraged to minimize revision risk.

More than 100,000 annual total knee replacement (TKR) procedures are recorded by the combined arthroplasty registries of Sweden, Australia, and Kaiser Permanente from the USA (1). Although survivorship of TKR is over 95% at 10 years, the frequency of the procedure creates a considerable number requiring revision (2,3).

Data from large arthroplasty registries is useful for studying TKR revision, and this gives "real-world" assessments as it describes community experience rather than that of a tertiary referral service (4). Combining data from multiple registries can not only increase the number available to study, but also reduce practice variation limitations and increase generalizability (1). Although individual patient data is ideal, there can be difficulties obtaining this due to patient privacy regulations and data security and ownership concerns, so, alternatively, summary data can be obtained and combined using meta-analytic techniques (1,5).

Studies of patient and prosthesis characteristics affecting TKR revision usually analyze all-cause revision (1,6). While there have been summaries of common revision diagnoses, including arthrofibrosis (7,8), fracture (9,10), infection (11,12), instability (13,14), loosening (15,16), pain (17,18), patellar pain (19,20), and wear (21,22), how patient and prosthesis factors relate to these different reasons for revision remains unclear.

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In a previous study using a multi-registry approach we found characteristics associated with overall revision rates of primary TKR (1). Now we analyze patient and prosthesis factors in relation to each common reason for revision.

Patients and methods

We obtained aggregate annual data for the period January 1, 2003 to December 31, 2019 for all first revision TKR procedures recorded in the Swedish Knee Arthroplasty Register (SKAR), the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR), and the Kaiser Permanente Joint Replacement Registry (KPJRR). We included revision TKR only where the primary TKR procedure was recorded in the study period (between 2003 and 2019) and the initial diagnosis was osteoarthritis (OA). Revisions of partial knee arthroplasties, revisions of primary TKR for pathologies other than OA, with primary procedures prior to 2003 or subsequent revisions of a previous revision, were excluded. The completeness of these registries exceeds 95% and loss to follow-up was less than 8% over the study period. Validation and quality control methods of these registries have been published (**2**,**23**,**24**).

During this period, there were 1,072,924 primary TKRs for OA recorded (188,290 from the SKAR, 663,982 from the AOANJRR, and 220,652 from the KPJRR). Of these, 36,626 were revised (5,613 from the SKAR, 24,931 from the AOANJRR, and 6,082 from the KPJRR) and this constitutes the study group. Revision knee replacements included revision procedures of a previous total knee replacement where 1 or more components were added, removed, or exchanged.

The reason for revision was determined from the revision diagnosis selected by the surgeon at the time of the revision procedure from a predetermined list, or specifically added. Multiple reasons could be listed. In Sweden, all operative reports were methodically read and from these the primary reason for revision was interpreted by registry staff. In the AOANJRR and KPJRR, when multiple reasons for revision were recorded, a diagnosis hierarchy was used to determine the most important reason for revision. In this study only 1 reason for revision was permitted for each revision procedure. Revision diagnoses were classified by a previously created harmonized table of equivalent diagnosis groups (**25**).

Patient factors recorded (for both primary and revision procedures) were age, sex, ASA class, and BMI. As the SKAR and AOANJRR began collecting ASA and BMI data at later time points, these categories permitted limited analyses. We analyzed 5 prosthesis factors: (i) Prosthesis constraint was divided into minimally stabilized (MS) (those that have a flat or dished tibial articulation, regardless of congruency), posterior stabilized (PS) (implants that provide posterior stability using a peg and box design), fully stabilized (FS) (implants with a large peg and box design designed to give some collateral as well as posterior stability), and hinged (implants with a hinge mechanism to link the femoral and tibial components); (ii) Fixation was cemented (both femoral and tibial components cemented), cementless (both components inserted without cement), and hybrid (tibial or femoral component only cemented); (iii) Bearing mobility was either mobile (inserts designed to move relative to the tibial base-plate) or fixed (inserts designed not to move relative to the tibial base-plate); (iv) Patellar resurfacing components were either used or not used; (v) Polyethylene type was ultra-high molecular weight polyethylene (UHMWPE), highly cross-linked (XLPE, classified as ultrahigh molecular weight polyethylene that has been irradiated by high dose [> 50 kGy] gamma or electron beam radiation) and highly cross-linked polyethylene with anti-oxidant (combining the anti-oxidants vitamin E and Covernox [DePuy Synthes. Warsaw, IN, USA]) (XLPE + AntiOx).

For the patient and prosthesis factor comparisons the 2 most common categories were selected for analysis. Age was divided into < 65 years and compared with ≥ 65 years of age. For the analyses of prosthesis constraint, MS were compared with PS, cement fixation was compared with cementless fixation, and for polyethylene type XLPE and XLPE + AntiOx were combined for comparison with UHMWPE.

Statistics

Proportions of the individual registry's reasons for revision and revision procedures were determined and compared. Mean time to revision for each reason was calculated.

As time-to-event data was not available for this study, categorical data was used to calculate odds ratios (OR) with 95% confidence intervals (CI) for patient and prosthesis factors for each reason for revision using the on-line GIGAcalculator (**26**). The number revised was considered with respect to the total number of primary procedures having that factor. Where the odds ratios for each registry were concordant and all either above or below 1, and the confidence interval did not contain 1 (i.e., a consistent and statistically significant association was found), these were chosen for meta-analysis. The Mantel–Haenszel random-effects method was used due to the event rate being low and the presence of inter-registry heterogeneity. RevMan version 5.4 (27) was used for the calculations. Heterogeneity was determined by I^2.

Ethics, data sharing, funding, and potential conflicts of interest

Ethics approval covering the SKAR data use was approved by the Ethics Board of Lund University (LU20-02). The AOANJRR is a declared a Commonwealth of Australia Quality Assurance Activity under section 124X of the Health Insurance Act, 1973. All AOANJRR studies are conducted in accordance with ethical principles of research (Helsinki Declaration II). Approval for inclusion of data from the Kaiser Permanente Joint Replacement Registry Institutional Review Board approval (#5488) was granted on August 18, 2021. A

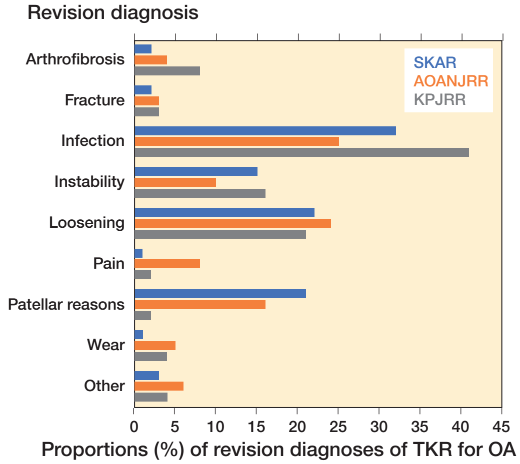


Figure 1. Proportions of revision diagnoses of TKR for OA.

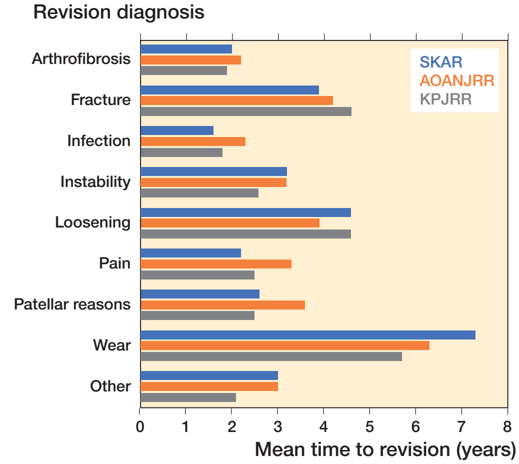


Figure 2. Mean time to revision (years) by revision reason.

data sharing agreement for the purpose of this study was finalized on December 10, 2020 by the directors of the SKAR, AOANJRR, and KPJRR. There was no funding. There are no conflicts of interest.

Results

The mean patient ages of primary TKR were similar to those revised, while there were marginally greater proportions of males undergoing revision compared with primary TKR. ASA status and BMI for revised patients both showed a small shift in proportion to higher categories. Prosthetic factor comparisons between primary TKR and those revised showed small increases in proportions of PS components revised, mobile-bearing (MB) prostheses, and those using UHMWPE, but no consistent differences regarding fixation type or patellar component use (Table 1, see Supplementary data).

Reasons for revision

Infection, loosening, patellar reasons, and instability were the most common reasons for revision, except for the KPJRR where revisions for patellar reasons were infrequent (Figure 1). The mean times to revision were shortest for infection and arthrofibrosis and longest for wear, loosening, and fracture (Figure 2).

Patient factors for each of the more common reasons for revision were analyzed (Table 2). The mean age at time of revision ranged from 64 to 77 years, being lowest for revisions for arthrofibrosis and highest for revisions for fracture. The

Table 2. Patient factors for all primary TKR for OA 2003–2019 and their revisions

	Total	Female n (%)	Mean age (SD)	Years to revision (SD)	ASA 1–2 n (%)	BMI > 30 n (%)
SKAR						
All primaries	188,290	109,060 (58)	70 (9)		112,916 (83)	52,001 (38)
Revised for						
Arthrofibrosis	86	43 (50)	65 (11)	2.0 (2.2)	64 (89)	25 (28)
Fracture	105	92 (88)	73 (9)	3.9 (4.3)	50 (59)	29 (35)
Infection	1,812	771 (43)	70 (9)	1.6 (2.7)	873 (61)	605 (44)
Instability	857	572 (67)	67 (9)	3.2 (2.9)	553 (77)	299 (41)
Loosening	1,246	769 (62)	69 (9)	4.6 (3.6)	817 (76)	512 (47)
Pain	72	48 (67)	66 (9)	2.2 (1.6)	16 (77)	10 (48)
Patellar reasons	1,205	755 (63)	69 (9)	2.6 (2.4)	735 (80)	386 (42)
Wear	32	15 (47)	66 (8)	7.3 (3.9)	22 (76)	14 (48)
AOANJRR						
All primaries	663,982	372,774 (56)	69 (9)		208,946 (59)	145,865 (55)
Revised for						
Arthrofibrosis	926	503 (54)	66 (9)	2.2 (2.1)	325 (61)	225 (24)
Fracture	781	594 (76)	73 (10)	4.2 (4.2)	180 (35)	194 (54)
Infection	6,128	2,401 (39)	69 (10)	2.3 (2.9)	1,299 (35)	1,387 (60)
Instability	2,437	1,464 (60)	67 (10)	3.2 (3.1)	864 (51)	829 (63)
Loosening	5,888	3,342 (57)	67 (9)	3.9 (3.4)	1,664 (52)	1,470 (64)
Pain	2,040	1,165 (57)	68 (9)	3.3 (2.8)	610 (57)	500 (63)
Patellar reasons	4,003	2,297 (57)	69 (9)	3.6 (3.1)	1,292 (56)	954 (60)
Wear	1,159	650 (56)	68 (9)	6.3 (4.1)	336 (50)	308 (61)
KPJRR						
All primaries	220,652	135,715 (61)	68 (8)		127,637 (58)	119,374 (54)
Revised for						
Arthrofibrosis	495	296 (60)	64 (9)	1.9 (1.8)	296 (67)	255 (52)
Fracture	164	138 (84)	77 (10)	4.6 (4.1)	46 (32)	76 (47)
Infection	2,469	1,180 (48)	69 (10)	1.8 (2.5)	715 (37)	1,330 (54)
Instability	979	622 (64)	65 (9)	2.6 (2.5)	492 (56)	562 (58)
Loosening	1,256	788 (63)	66 (9)	4.6 (3.3)	630 (54)	795 (63)
Pain	146	94 (64)	66 (9)	2.5 (2.1)	83 (65)	81 (56)
Patellar reasons	126	78 (62)	67 (9)	2.5 (2.2)	64 (57)	75 (60)
Wear	197	114 (58)	67 (9)	5.7 (4.2)	96 (51)	114 (58)

Note: Mean age (at time of revision) in years, proportions for ASA and BMI exclude missing values.

Table 3. Prosthesis factors for all primary TKR for OA 2003–2019 and their revisions. Values are count (%)

	Total	MS	PS	Cemented	Cementless	Hybrid	Fixed bearing	UHMWPE	XLPE	Patellar resurfacing
SKAR										
All primaries	188,290	175,667 (94)	11,340 (6)	180,220 (96)	7,424 (4)	136 (0)	186,680 (99)	162,648 (86)	24,968 (13)	7,975 (4)
revised for										
Arthrofibrosis	86	73 (85)	11 (13)	81 (94)	5 (6)	0 (0)	82 (95)	67 (78)	18 (21)	10 (12)
Fracture	105	86 (82)	15 (14)	103 (98)	2 (2)	0 (0)	104 (99)	96 (91)	9 (9)	10 (10)
Infection	1,812	1,576 (87)	194 (11)	1,724 (95)	81 (4)	0 (0)	1,780 (98)	1,525 (84)	284 (15)	107 (6)
Instability	857	772 (90)	76 (9)	782 (91)	70 (8)	2 (0)	843 (98)	745 (87)	106 (12)	39 (5)
Loosening	1,246	1,110 (89)	123 (10)	1,220 (98)	18 (1)	4 (0)	1,206 (97)	1,143 (92)	99 (8)	139 (11)
Pain	72	69 (96)	1 (1)	69 (96)	2 (3)	1 (1)	72 (100)	71 (99)	1 (1)	5 (7)
Patellar reasons	1,205	1,120 (93)	76 (6)	1,143 (95)	61 (5)	0 (0)	1,175 (98)	1,086 (89)	133 (11)	15 (1)
Wear	32	32 (100)	0 (0)	26 (81)	6 (19)	0 (0)	32 (100)	26 (81)	6 (19)	8 (25)
AOANJRR										
All primaries	663,982	487,626 (73)	172,530 (26)	389,650 (59)	120,616 (18)	147,232 (23)	539,194 (81)	395,665 (60)	268,036 (41)	375,409 (57)
revised for										
Arthrofibrosis	926	644 (70)	281 (30)	508 (55)	238 (26)	169 (18)	712 (77)	632 (68)	294 (32)	490 (53)
Fracture	781	503 (64)	256 (33)	413 (53)	185 (24)	168 (22)	606 (78)	583 (75)	198 (25)	431 (53)
Infection	6,128	3,948 (64)	2,062 (34)	3,853 (63)	1,011 (16)	1,186 (19)	4,916 (80)	3,994 (65)	2,133 (35)	3,564 (58)
Instability	2,437	1,693 (69)	720 (30)	1,131 (55)	527 (22)	549 (23)	1904 (78)	1,736 (71)	701 (29)	1,368 (56)
Loosening	5,888	3,839 (65)	2,025 (34)	3,095 (52)	1,570 (27)	1,143 (19)	4,117 (70)	4,725 (80)	1,159 (20)	3,169 (54)
Pain	2,040	1,419 (70)	613 (30)	1,072 (53)	483 (24)	447 (22)	1,524 (75)	1,564 (77)	474 (23)	632 (31)
Patellar reasons	4,003	2,940 (73)	1,050 (26)	1,879 (97)	1,138 (28)	903 (23)	2,970 (74)	3,174 (79)	829 (20)	91 (2)
Wear	1,159	950 (82)	208 (18)	386 (33)	574 (50)	187 (16)	671 (58)	1,027 (89)	132 (11)	555 (48)
KPJRR										
All primaries	220,652	66,489 (30)	146,780 (67)	208,391 (94)	3746 (2)	6,387 (3)	202,426 (92)	147,384 (67)	60,906 (28)	215,924 (98)
revised for										
Arthrofibrosis	495	179 (36)	304 (61)	467 (94)	11 (2)	12 (2)	434 (88)	354 (72)	123 (25)	486 (98)
Fracture	164	22 (13)	132 (80)	151 (92)	3 (2)	5 (3)	148 (90)	128 (78)	22 (13)	162 (99)
Infection	2,469	639 (26)	1,727 (70)	2,344 (95)	39 (2)	60 (2)	2,226 (90)	1,762 (71)	615 (25)	2,419 (98)
Instability	979	287 (29)	659 (67)	912 (93)	20 (2)	34 (3)	845 (86)	670 (68)	268 (27)	960 (98)
Loosening	1,256	296 (24)	936 (75)	1,150 (92)	46 (4)	50 (4)	1,092 (87)	1,022 (81)	189 (15)	1,239 (99)
Pain	146	46 (32)	95 (65)	130 (89)	12 (8)	3 (2)	123 (84)	106 (73)	29 (20)	137 (94)
Patellar reasons	126	34 (27)	91 (72)	113 (90)	6 (5)	6 (5)	107 (85)	92 (73)	30 (24)	102 (81)
Wear	197	72 (37)	118 (60)	174 (88)	17 (9)	4 (2)	172 (87)	133 (68)	55 (28)	194 (98)

Note: MS = minimally stabilized; PS = Posterior stabilized. XLPE includes XLPE and XLPE with antioxidant. Patellar resurfacing is patellar resurfacing component used.

proportion of females revised ranged from 39% to 88%, being lowest for revisions for infection and highest for revisions for fracture.

Prosthesis factors for the individual reasons for revision are presented in Table 3. These are the characteristics of the components used in the primary procedure that was revised. For each registry, the number and proportions for these factors for all primary procedures from which these revisions were derived are also listed for comparison. The proportions of revised TKR to primary TKR in each registry were compared for the 8 revision diagnoses, giving 24 comparisons. The proportion of revised compared with primary TKR using UHMWPE was higher in 21 of 24 comparisons, for both cementless and PS prostheses in 15 comparisons, while use of a fixed bearing was only higher in 2 comparisons.

Association of prosthesis factors with reasons for revision

Odds ratio determinations for individual reasons for revision showed that there was inconsistency between registries for many of the factors studied (Table 4, see Supplementary data). There was insufficient data for analysis of ASA or BMI. Where consistency was found, a summary effect for revision risk was determined by meta-analysis (Table 5).

Analysis of arthrofibrosis showed that young age (OR 2.0; CI 1.4–2.7) and MB designs (OR 1.7; CI 1.1–2.5) were risk factors for revision. Higher odds for revision for fracture were seen for females (OR 3.2; CI 2.2–4.8), age 65 years and over (OR 2.8; CI 1.9–4), and with PS prostheses (OR 2.1; CI 1.3–3.5). Factors affecting revision for infection were male sex (OR 1.9; CI 1.7–2.1), and PS components (OR 1.5; CI 1.2–1.8). Younger age (OR 1.5; CI 1.3–1.8) and MB designs (OR 1.5; CI 1.1–2.2) had higher odds for revision for instability, while PS (OR 1.5; CI 1.4–1.6), as well as MB designs (OR 2.2; CI 1.6–3) and UHMWPE inserts (OR 2.3; CI 1.8–2.9) had higher odds for revision for loosening. There was no consistency found when factors were assessed with regard to revision for pain. MB components (OR 2.0; CI 1.2–3.3) and not using a patellar component (OR 13.6; CI 2.1–87.2) increased odds for revision for patellar reasons. Cementless fixation (OR 4.9; CI 4.3–5.5) increased the odds for revision for wear. The meta-analyses showed substantial or considerable statis-

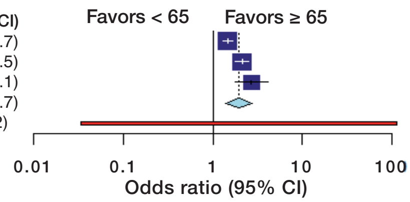
Table 5. Meta-analysis of odds ratios for the selected patient and prosthesis factors for each reason for revision, using the Mantel–Haenszel random-effects method

1. Arthrofibrosis

Age and revision for arthrofibrosis

	< 65		≥ 65		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	389	220,574	537	443,408	1.5 (1.3–1.7)
KPJRR	274	81,608	221	139,044	2.1 (1.8–2.5)
SKAR	47	58,275	39	130,015	2.7 (1.8–4.1)
Total		360,457		712,247	1.9 (1.4–2.7)
Predicition interval					(0.0–112.2)

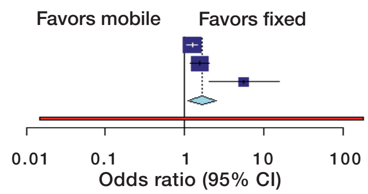
Heterogeneity: χ^2_2 = 15.7 (p < 0.001), I^2 = 87%
Test for overall effect: z = 3.87 (p < 0.001)



Bearing mobility and revision for arthrofibrosis

	Mobile		Fixed		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	214	129,788	712	539,194	1.2 (1.1–1.5)
KPJRR	61	18,226	434	202,426	1.6 (1.2–2.0)
SKAR	4	1,610	82	186,680	5.7 (2.1–16)
Total		149,624		928,300	1.7 (1.1–2.5)
Predicition interval					(0.0–184.3)

Heterogeneity: χ^2_2 = 9.97 (p = 0.007), I^2 = 80%
Test for overall effect: z = 2.38 (p = 0.02)

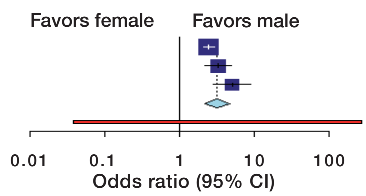


2. Fracture

Sex and revision for fracture

	Female		Male		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	594	372,774	187	291,208	2.5 (2.1–2.9)
KPJRR	138	135,715	26	84,937	3.3 (2.2–5.1)
SKAR	92	109,060	13	79,240	5.1 (2.9–9.2)
Total		617,549		455,385	3.2 (2.2–4.8)
Predicition interval					(0.0–276.1)

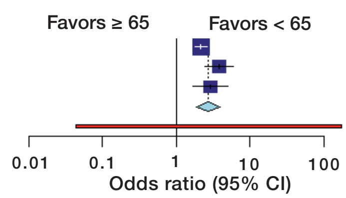
Heterogeneity: χ^2_2 = 6.67 (p = 0.04), I^2 = 70%
Test for overall effect: z = 5.85 (p < 0.001)



Age and revision for fracture

	< 65		≥ 65		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	146	220,574	635	443,408	2.2 (1.8–2.6)
KPJRR	22	81,608	142	139,044	3.8 (2.4–5.9)
SKAR	14	58,275	91	130,015	2.9 (1.7–5.1)
Total		360,457		712,467	2.7 (1.9–4.0)
Predicition interval					(0.0–174.5)

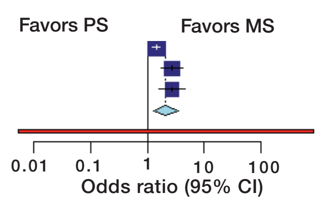
Heterogeneity: χ^2_2 = 5.69 (p = 0.06), I^2 = 65%
Test for overall effect: z = 5.29 (p < 0.001)



Constraint and revision for fracture

	MS		PS		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	256	172,530	503	487,626	1.4 (1.2–1.7)
KPJRR	132	146,780	22	664,489	2.7 (1.7–4.3)
SKAR	15	11,340	86	175,667	2.7 (1.6–4.7)
Total		330,650		729,782	2.1 (1.3–3.5)
Predicition interval					(0.0–839.0)

Heterogeneity: χ^2_2 = 10.7 (p = 0.05), I^2 = 81%
Test for overall effect: z = 2.89 (p = 0.004)

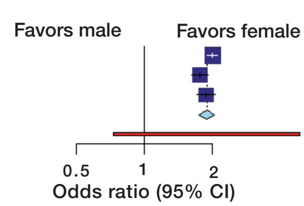


3. Infection

Sex and revision for infection

	Female		Male		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	2,401	372,774	3,727	291,208	2.0 (1.9–2.1)
KPJRR	1,180	135,715	1,289	84,937	1.8 (1.6–1.9)
SKAR	771	109,060	1,041	79,230	1.9 (1.7–2.1)
Total		617,549		455,375	1.9 (1.7–2.0)
Predicition interval					(0.0–4.9)

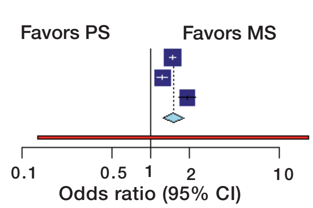
Heterogeneity: χ^2_2 = 7.49 (p = 0.02), I^2 =73%
Test for overall effect: z = 15.0 (p < 0.001)



Constraint and revision for infection

	PS		MS		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	2,062	172,530	3,948	478,626	1.5 (1.4–1.6)
KPJRR	1,727	146,780	639	66,489	1.2 (1.1–1.3)
SKAR	194	11,340	1,576	175,667	1.9 (1.7–2.2)
Total		330,650		729,782	1.5 (1.2–1.8)
Predicition interval					(0.1–17.0)

Heterogeneity: χ^2_2 = 27.1 (p < 0.001), I^2 = 93%
Test for overall effect: z = 4.11 (p < 0.001)



tical heterogeneity for all but 2 measures (fixation and revision for wear and prosthesis constraint and revision for loosening). It was only for the analysis of fixation for revision for wear that the prediction interval did not contain 1.

Discussion

We found infection, loosening, instability, and patellar reasons were the most common diagnoses for revision of TKR for OA in all 3 registries, with the only difference seen in the KPJRR where 98% of TKR had a primary patellar resurfacing and patellar causes for revision were rare. These findings, along with the timing of these revisions, are consistent with previous studies (25,28,29). When patient and prosthesis factors for revision reasons were studied, 15 of 56 possible factor/reason combinations showed between-registry consistency, varying from 3 concordant factors for each of revision for fracture and loosening, and no factor consistency for revision for pain.

Where discrepancy in odds ratio was found, this could mean that there is no link between the factor and revision reason (such as patellar component use and revision for instability), the numbers revised were too small to detect a difference (such as revisions for wear in the SKAR), or there may have been practice variations and individual prosthesis performance differences within the factor studied. There may also be between-surgeon differences in selecting revision diagnoses (for instance, due to multiple failure mechanisms being present, loosening recorded when a low-grade infection is detected later, or distinguishing between pain and patellar pain).

Younger age and MB designs were risk factors for revision for arthrofibrosis. Arthrofibrosis, or postoperative stiffness, is poorly understood but thought to involve an exaggerated soft tissue inflammation (8). While there is

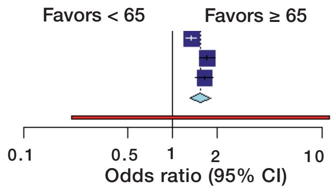
Table 5 continued

4. Instability

Age and revision for instability

	< 65		≥ 65		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	974	220,574	1,463	443,408	1.3 (1.2–1.5)
KPJRR	489	81,608	490	139,044	1.7 (1.5–1.9)
SKAR	362	58,275	495	130,015	1.6 (1.4–1.9)
Total		360,457		712,467	1.5 (1.3–1.8)
Predicition interval					(0.2–11.3)

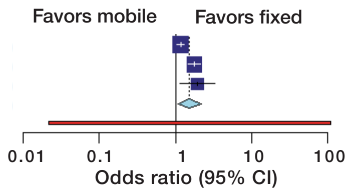
Heterogeneity: χ^2_2 = 12.7 (p = 0.002), I^2 = 84%
Test for overall effect: z = 5.16 (p < 0.001)



Bearing mobility and revision for instability

	Mobile		Fixed		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	533	129,788	1,904	539,194	1.2 (1.1–1.3)
KPJRR	134	18,226	845	202,426	1.8 (1.5–2.1)
SKAR	14	1,610	843	186,680	1.9 (1.1–3.3)
Total		149,624		928,300	1.5 (1.1–2.2)
Predicition interval					(0.0–107.7)

Heterogeneity: χ^2_2 = 18.0 (p < 0.001), I^2 = 89%
Test for overall effect: z = 2.30 (p = 0.02)

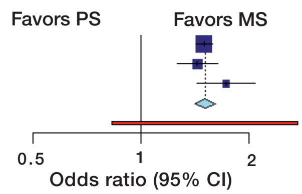


5. Loosening

Constraint and revision for loosening

	PS		MS		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	2,025	172,530	3,839	478,626	1.5 (1.4–1.6)
KPJRR	936	146,780	296	66,489	1.4 (1.3–1.6)
SKAR	123	11,340	1,110	175,667	1.7 (1.4–2.1)
Total		330,650		729,782	1.5 (1.4–1.6)
Predicition interval					(0.8–2.7)

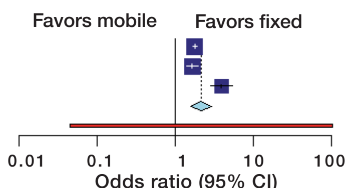
Heterogeneity: χ^2_2 = 2.57 (p < 0.3), I^2 = 22%
Test for overall effect: z = 11.9 (p < 0.001)



Bearing mobility and revision for loosening

	Mobile		Fixed		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	1,771	129,788	4,117	539,194	1.8 (1.7–1.9)
KPJRR	164	18,226	1,092	202,426	1.7 (1.4–2.0)
SKAR	40	1,610	1,206	186,680	3.9 (2.8–5.4)
Total		149,624		928,300	2.2 (1.6–3.0)
Predicition interval					(0.0–103.3)

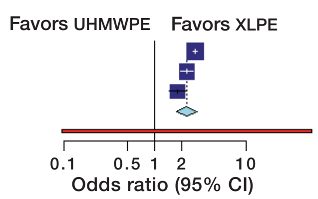
Heterogeneity: χ^2_2 = 23.4 (p < 0.001), I^2 = 91%
Test for overall effect: z = 4.85 (p < 0.001)



Polyethylene type and revision for loosening

	UHMWPE		XLPE		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	4,725	395,665	1,159	268,036	2.8 (2.6–3.0)
KPJRR	1,022	147,384	189	60,906	2.2 (1.9–2.6)
SKAR	1,143	162,648	99	24,968	1.8 (1.4–2.2)
Total		705,697		353,910	2.3 (1.8–2.9)
Predicition interval					(0.0–53.6)

Heterogeneity: χ^2_2 = 20.8 (p < 0.001), I^2 = 90%
Test for overall effect: z = 6.27 (p < 0.001)

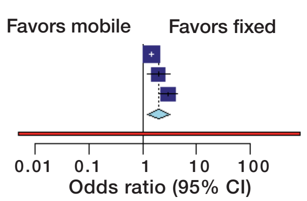


6. Patellar reasons

Bearing mobility and revision for patella reasons

	Mobile		Fixed		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	1,033	129,788	2,970	539,194	1.4 (1.3–1.6)
KPJRR	19	18,226	107	202,426	2.0 (1.2–3.2)
SKAR	30	1,610	1,175	186,680	3.0 (2.1–4.3)
Total		149,624		928,300	2.0 (1.2–3.3)
Predicition interval					(0.0–838,4)

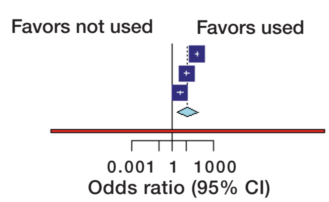
Heterogeneity: χ^2_2 = 15.9 (p < 0.001), I^2 = 87%
Test for overall effect: z = 2.75 (p = 0.006)



Patella usage and revision for patella reasons

	Not used		Used		
Source	Events	Total	Events	Total	OR (95% CI)
AOANJRR	3,912	258,573	2,970	375,409	63 (52–78)
KPJRR	24	4,728	102	215,924	11 (6.9–17)
SKAR	1,190	180,315	15	7,975	3.5 (2.1–5.9)
Total		149,624		599,308	14 (2.2–82)
Predicition interval					(0.0–15^{10})

Heterogeneity: χ^2_2 = 136 (p < 0.001), I^2 = 99%
Test for overall effect: z = 2.84 (p = 0.004)



no consensus regarding the influence of age on postoperative stiffness shown in a systematic review (7), arthrofibrosis was the most frequent cause for revision in a recent MB study (30).

Higher likelihood for revision for fracture was seen with female sex and age ≥ 65 years, consistent with previous findings (31), and the association with PS components has been related to excessive or eccentric "box" cuts and increased internal prosthetic constraint compared with cruciate-retaining designs (10,32).

The odds ratio for revision for infection was higher for males, as has previously been described (11,33). The increase in revision for infection with PS components has been reported (12,34), attributed to polyethylene debris and the associated joint response seen with these designs (34).

Revision for instability was associated with younger age, consistent with other results (13,14), while instability with MB prostheses has been described (35,36). Due to inter-registry differences in the odds ratios (which may relate to prosthesis use patterns) prosthesis constraint was not a factor chosen for further analysis for instability.

The fixation method had inconsistent odds ratios for revision for loosening, but there were associations identified with factors relating to the bearing. UHMWPE showed higher odds for revision for loosening than XLPE, while there was a greater risk with PS and MB designs. Previous studies have been variable, with some showing no difference between "conventional" polyethylene and XLPE (37), while others report findings similar to ours that may relate to biological reactions to wear products (16). Osteolysis may also be a common mechanism to explain the association of loosening with PS and MB components (21,38), which others claim relates simply to component design (39).

Odds ratio summaries showed no factor consistency in the analysis of revision for pain. Post-TKR pain is considered multifactorial, and often related to systemic conditions such as depression and catastrophizing (17), and it is not surprising that prosthesis factors showed no association in this study.

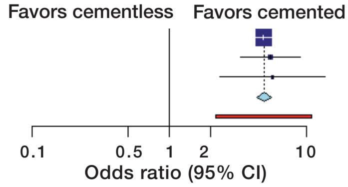
Table 5 continued

7. Wear

Fixation and revision for wear

Source	Cementless Events	Cementless Total	Cemented Events	Cemented Total	OR (95% CI)
AOANJRR	574	120,616	386	389,650	4.8 (4.2–5.5)
KPJRR	17	3,746	174	208,391	5.5 (3.3–9.0)
SKAR	6	7,424	26	180,220	5.6 (2.3–14)
Total		131,786		778,261	4.9 (4.3–5.5)
Predicition interval					(2.2–10.9)

Heterogeneity: $\chi^2_2 = 0.32$ (p = 0.9), $I^2 = 0\%$
Test for overall effect: z = 25.,1 (p < 0.001)



The strongest association between prosthesis factors and revision was shown in the analysis of patellar component use and revision for patellar reasons, where not using a patellar component showed much higher odds for revision for these diagnoses. Although some controversy may remain around function and pain relief regarding patellar component use (40), there seems less doubt that using a patellar component leads to a lower rate of revision for this reason (41). The finding that MB prostheses also showed higher odds for revision for patellar reasons is contrary to a study from the New Zealand Joint Registry that found fixed-bearing PS prostheses had a higher rate of secondary patellar resurfacing than mobile-bearing designs (42). This difference may relate to the specific prostheses used in each registry, or possibly to the common "gap balancing" technique for implantation, where femoral component rotation is determined after ligament releases (43).

Prostheses with cementless fixation had higher odds for revision for wear compared with cemented components. While there seems no direct link of the implant–bone interface to the bearing, cementless fixation may have been selected for more active patients (44). Surgeons may also have difficulty deciding between wear and loosening as the primary mechanism leading to revision (25). The lack of further associations with wear may be due to the relative rarity of revisions for this diagnosis, particularly in Sweden.

This study has a number of limitations. Despite the study design that included large data sets from each registry, some revision reasons still have only small numbers for analysis and more robust conclusions would require the inclusion of data from more registries. Only 7 patient and prosthesis factors were included, and there may be other influences on revision. We used a categorical distinction of revised/not revised as the outcome measure, and perhaps more detail could have been obtained had time-to-event data been available. In addition, odds ratios for each reason for revision were considered separately, comparing the number revised for that diagnosis with the number not revised, and this method does not take into account TKR revised for other competing reasons, or those who died. Additionally, the number revised for each reason most likely understates the true number of revisions as, in order to assess the proportion of primary TKRs revised, toward the censoring endpoint some TKRs were included that did not have time to be revised. This aspect would have a greater effect on those reasons with longer times to revision. Each factor was analyzed independently and there may be interactions between factors. We used categories for each prosthesis factor analyzed and there may be prosthesis performance differences within these categories. We used the Mantel–Haenszel method for calculating a summary effect size, and this is known to become less accurate with small event rates (45).

In summary, age < 65 years was associated with lower odds of revision for fracture but higher odds of revision for arthrofibrosis and instability. Females had higher odds of revision for fracture, but lower odds of revision for infection. PS prostheses had a higher likelihood of revision for infection, fracture, and loosening, while MB prostheses had higher odds of revision for arthrofibrosis, instability, and for patellar reasons, cementless fixation showed higher odds of revision for wear, and not using a patellar component increased the likelihood of revision for patellar reasons.

Patients could be counselled regarding specific risks for their age and sex, while the use of minimally stabilized, fixed-bearing, cemented prostheses and patellar components is encouraged to minimize revision risk. However, the final choice of implant characteristics may need to be modified according to specific patient circumstances.

PLL: Literature search, study design, methodology determination, data collection, data analysis, data synthesis, manuscript writing. AWD: Study design, interpretation of data, manuscript preparation. OR: Data analysis. HAP: Data analysis, manuscript preparation. SEG: Interpretation of data, manuscript preparation.

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Supplementary data

Table 1. Summary of patient and prosthesis factors for primary and revised TKR for OA 2003–2019 by registry. Values are count (%) unless otherwise specified

	Primary SKAR	Primary AOANJRR	Primary KP	Revised SKAR	Revised AOANJRR	Revised KP
Total number of TKR	188,290	663,982	220,652	5,613	24,931	6,082
Patient factors						
Sex						
Males	79,230 (42)	291,208 (44)	84,937 (38)	2,430 (43)	11,683 (47)	2,641 (43)
Females	109,060 (58)	372,774 (56)	135,715 (62)	3,183 (57)	13,248 (53)	3,441 (57)
Mean age (SD)	69.5 (8.9)	68.5 (9.1)	67.6 (8.9)	69.2 (9.3)	68.2 (9.4)	67.1 (9.6)
Age groups						
< 55	11,164 (6)	43,508 (7)	15,915 (7)	411 (7)	1,886 (8)	594 (10)
55–64	47,111 (25)	177,066 (27)	65,693 (30)	1,436 (26)	6,698 (27)	1,850 (30)
65–74	74,830 (40)	263,105 (40)	88,065 (40)	2,141 (38)	9,850 (40)	2,220 (37)
≥ 75	55,185 (29)	180,303 (27)	50,979 (23)	1,625 (29)	6,497 (26)	1,418 (23)
ASA from year	2009	2013	2003	2009	2013	2003
ASA 1	24,112 (13)	20,306 (3)	3,431 (2)	525 (11)	524 (4)	34 (1)
ASA 2	88,804 (47)	188,640 (28)	124,206 (56)	2,728 (56)	6,507 (45)	2,504 (41)
ASA 3	22,426 (12)	128,551 (19)	73,502 (33)	1,193 (25)	7,002 (48)	2,527 (42)
ASA 4	249 (0)	3,672 (1)	1,769 (1)	33 (1)	527 (4)	138 (2)
ASA 5	9 (0)	10 (0)	13 (0)	0 (0)	6 (0)	5 (0)
Missing	1,348 (1)	14,891 (2)	17,731 (8)	363 (7)	0 (0)	874 (14)
Total	136,948	356,070	220,652	4,842	14,566	6,082
BMI from year	2009	2015	2003	2009	2015	2003
Underweight (< 18.5)	214 (0)	439 (0)	393 (0)	7 (0)	29 (0)	20 (0)
Normal (18.5–24.9)	24,483 (13)	25,581 (4)	25,849 (12)	751 (15)	964 (9)	752 (12)
Pre-obese (25.0–29.9)	58,839 (31)	77,407 (12)	69,110 (31)	1,762 (36)	2,940 (29)	1,846 (30)
Obese 1 (30.0–34.9)	38,000 (20)	76,861 (12)	66,968 (30)	1,318 (27)	3,121 (31)	1,767 (29)
Obese 2 (35.0–39.9)	11,565 (6)	42,505 (6)	37,882 (17)	481 (10)	1,863 (18)	1,068 (18)
Obese 3 (≥ 40.0)	2,436 (1)	26,499 (4)	14,524 (7)	126 (3)	1,242 (12)	583 (10)
Missing	1,411 (1)	16,641 (3)	5,926 (3)	462 (9)	0 (0)	46 (1)
Total	136,948	265,933	220,652	4,907	10,159	6,082
Prosthesis factors						
Prosthesis constraint						
Minimally stabilized	175,667 (93)	487,626 (73)	66,489 (30)	5,025 (90)	16,973 (68)	1,643 (27)
Posterior stabilized	11,340 (6)	172,530 (26)	146,780 (67)	504 (9)	7,725 (31)	4,232 (70)
Fully stabilized	758 (0)	2,519 (0)	2310 (1)	38 (1)	139 (1)	91 (1)
Hinged	470 (0)	1,133 (0)	64 (0)	41 (1)	86 (0)	5 (0)
Missing	55 (0)	174 (0)	5,009 (2)	5 (0)	8 (0)	111 (2)
Fixation						
Both cemented	180,220 (96)	389,650 (59)	208,391 (94)	5,336 (95)	13,353 (54)	5,671 (93)
Both cementless	7,424 (4)	120,616 (18)	3,746 (2)	254 (5)	6,130 (25)	163 (3)
Tibia only cemented	136 (0)	147,232 (22)	6,387 (3)	7 (0)	5,050 (20)	183 (3)
Femur only cemented	277 (0)	6,484 (1)	357 (0)	7 (0)	398 (2)	15 (0)
Missing	233 (0)	0 (0)	1,771 (1)	9 (0)	0 (0)	50 (1)
Bearing mobility						
Fixed	186,680 (99)	539,194 (81)	202,426 (92)	5,489 (98)	18,575 (75)	5,371 (88)
Mobile	1,461 (1)	124,614 (19)	13,208 (6)	116 (2)	6,348 (25)	600 (10)
Missing	149 (0)	174 (0)	5,018 (2)	8 (0)	8 (0)	111 (2)
Patellar component						
Used	7,975 (4)	375,409 (57)	215,924 (98)	345 (6)	11,252 (45)	5,941 (98)
Not used	180,315 (96)	288,573 (43)	4,728 (2)	5,268 (94)	13,679 (55)	141 (2)
Polyethylene type						
UHMWPE	162,648 (86)	395,665 (60)	147,384 (67)	4,920 (88)	18,569 (74)	4,448 (73)
XLPE	24,473 (13)	230,781 (35)	36,750 (17)	665 (12)	5,788 (23)	1,002 (16)
XLPE + AntiOx.	495 (0)	37,255 (6)	24,156 (11)	10 (0)	567 (2)	387 (6)
Missing	674 (0)	281 (0)	12,362 (6)	18 (0)	7 (0)	245 (4)

Table 4. Odds ratios with 95% confidence intervals for each reason for revision

	Patient factors		Prosthesis factors				
	Sex F vs. M	Age < 65 vs. ≥ 65	Constraint PS vs. MS	Cement no vs. yes	Bearing mobility Mobile vs. fixed	Poly type UHMWPE:XLPE	Patellar component used no vs. yes
Arthrofibrosis							
SKAR	0.7 (0.5–1.1)	2.7 (1.8–4.1) [a]	2.3 (1.2–4.4) [a]	1.5 (0.6–3.7)	5.7 (2.1–16) [a]	0.6 (0.4–1.0)	0.3 (0.2–0.7) [b]
AOANJRR	0.7 (0.6–0.8) [b]	1.5 (1.3–1.7) [a]	1.2 (1.1–1.4) [a]	1.5 (1.3–1.8) [a]	1.3 (1.1–1.5) [a]	1.5 (1.3–1.7) [a]	1.6 (1.0–2.3)
KPJRR	0.9 (0.8–1.1)	2.1 (1.8–2.5) [a]	0.8 (0.6–0.9) [b]	1.3 (0.7–2.4)	1.6 (1.2–2.0) [a]	1.2 (1.0–1.5)	0.9 (0.4–1.6)
Fracture							
SKAR	5.1 (2.9–9.2) [a]	0.3 (0.2–0.6) [b]	2.7 (1.6–4.7) [a]	0.5 (0.1–1.9)	1.1 (0.2–8.0)	1.6 (0.8–3.2)	0.4 (0.2–0.8) [b]
AOANJRR	2.5 (2.1–2.9) [a]	0.5 (0.4–0.6) [b]	1.4 (1.2–1.7) [a]	1.5 (1.2–1.7) [a]	1.2 (1.0–1.4)	2.0 (1.7–2.4) [a]	1.2 (1.0–1.4)
KPJRR	3.3 (2.2–5.0) [a]	0.3 (0.2–0.4) [b]	2.7 (1.7–4.3) [a]	1.1 (0.4–3.5)	1.2 (0.7–2.0)	2.4 (1.5–3.8) [a]	0.6 (0.1–2.3)
Infection							
SKAR	0.5 (0.5–0.6) [b]	0.8 (0.7–0.9) [b]	1.9 (1.7–2.2) [a]	1.1 (0.9–1.4)	2.1 (1.5–3.0) [a]	0.8 (0.7–0.9) [b]	0.7 (0.6–0.9) [b]
AOANJRR	0.5 (0.5–0.5) [b]	0.9 (0.9–1.0)	1.5 (1.4–1.6) [a]	0.9 (0.8–0.9) [b]	1.0 (1.0–1.1)	1.0 (0.9–1.0)	1.0 (1.0–1.1)
KPJRR	0.6 (0.5–0.6) [b]	0.9 (0.8–0.9) [b]	1.2 (1.1–1.3) [a]	0.9 (0.7–1.3)	1.2 (1.1–1.4) [a]	1.2 (1.1–1.3) [a]	0.9 (0.7–1.3)
Instability							
SKAR	1.5 (1.3–1.7) [a]	1.6 (1.4–1.9) [a]	1.5 (1.2–1.9) [a]	2.2 (1.7–2.8) [a]	1.9 (1.1–3.3) [a]	1.1 (0.9–1.3)	0.9 (0.7–1.3)
AOANJRR	1.2 (1.1–1.3) [a]	1.3 (1.2–1.5) [a]	1.2 (1.1–1.3) [a]	1.5 (1.4–1.7) [a]	1.2 (1.1–1.3) [a]	1.7 (1.5–1.8) [a]	1.1 (1.1–1.2) [a]
KPJRR	1.1 (1.0–1.2)	1.7 (1.5–1.9) [a]	1.0 (0.9–1.2	1.2 (0.8–1.9)	1.8 (1.5–2.1) [a]	1.0 (0.9–1.2)	0.9 (0.6–1.4)
Loosening							
SKAR	1.2 (1.1–1.3) [a]	1.2 (1.0–1.3)	1.7 (1.4–2.1) [a]	0.4 (0.2–0.6) [b]	3.9 (2.9–5.4) [a]	1.8 (1.4–2.2) [a]	0.4 (0.3–0.4) [b]
AOANJRR	1.0 (1.0–1.1)	1.2 (1.2–1.3) [a]	1.5 (1.4–1.6) [a]	1.7 (1.6–1.8) [a]	1.8 (1.7–1.9) [a]	2.8 (2.6–3.0) [a]	1.3 (1.2–1.3) [a]
KPJRR	1.1 (0.9–1.2)	1.3 (1.1–1.4) [a]	1.4 (1.3–1.6) [a]	2.2 (1.7–3.0) [a]	1.7 (1.4–2.0) [a]	2.2 (1.9–2.6) [a]	0.6 (0.4–1.0)
Pain							
SKAR	1.5 (0.9–2.4)	3.0 (1.9–4.7) [a]	0.2 (0.0–1.6)	0.7 (0.2–2.9)	n.a.	11 (1.5–79) [a]	0.1 (0.0–0.1) [b]
AOANJRR	1.0 (1.0–1.1)	1.0 (0.9–1.1)	1.2 (1.1–1.3) [a]	1.5 (1.3–1.6) [a]	1.4 (1.3–1.6) [a]	2.2 (2.0–2.5) [a]	3.3 (3.0–36) [a]
KPJRR	1.1 (0.8–1.6)	1.6 (1.1–2.2) [a]	0.9 (0.7–1.3)	5.2 (2.9–9.3) [a]	2.1 (1.3–3.3) [a]	1.5 (1.0–2.3)	3.0 (1.5–5.9) [a]
Patellar reasons							
SKAR	1.2 (1.1–1.4) [a]	1.1 (1.0–1.3)	1.1 (0.8–1.3)	1.3 (1.0–1.7)	3.0 (2.1–4.3) [a]	1.3 (1.1–1.5) [a]	3.5 (2.1–5.9) [a]
AOANJRR	1.1 (1.0–1.1)	1.0 (0.9–1.0)	1.0 (1.0–1.1)	2.0 (1.8–2.1) [a]	1.5 (1.4–1.6) [a]	2.6 (2.4–2.8) [a]	63 (52–78) [a]
KPJRR	1.0 (0.7–1.5)	1.2 (0.8–1.7)	0.4 (0.3–0.5) [b]	3.0 (1.3–6.7) [a]	2.0 (1.2–3.2) [a]	1.3 (0.8–1.9)	11 (6.9–17) [a]
Wear							
SKAR	0.6 (0.3–1.3)	2.0 (1.0–3.9)	n.a.	5.6 (2.3–14) [a]	n.a.	0.7 (0.3–1.6)	0.1 (0.1–0.3) [b]
AOANJRR	1.0 (0.9–1.1)	1.0 (0.9–1.1)	0.6 (0.5–0.7) [b]	4.8 (4.2–5.5) [a]	3.0 (2.7–3.4) [a]	5.3 (4.4–6.3) [a]	1.6 (1.4–1.8) [a]
KPJRR	0.9 (0.7–1.1)	1.1 (0.8–1.4)	0.7 (0.6–1.0)	5.5 (3.3–9.0) [a]	1.6 (1.1–2.5) [a]	1.0 (0.7–1.4)	0.7 (0.2–2.2)

[a] Significant > 1
[b] Significant < 1
n.a. = not applicable (numbers too small to calculate).