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Projections and Epidemiology of Revision Hip and Knee Arthroplasty in the United States to 2030

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Abstract

Background—As the incidence of primary total joint arthroplasty rises in the United States, it is important to investigate how this will impact rates of revision arthroplasty. The purpose of this study was to analyze the incidence and future projections of revision total hip arthroplasty (rTHA) and revision total knee arthroplasty (rTKA) to 2030. Anticipating surgical volume will aid surgeons in designing protocols to efficiently and effectively perform rTHA/rTKA.

Methods—The national inpatient sample was queried from 2002 to 2014 for all rTHA/rTKA. Using previously validated measures, Poisson and linear regression analyses were performed to project annual incidence of rTHA/rTKA to 2030, with subgroup analyses on modes of failure and age.

Results—In 2014, there were 50,220 rTHAs and 72,100 rTKAs. From 2014 to 2030, rTHA incidence is projected to increase by between 43% and 70%, whereas rTKA incidence is projected to increase by between 78% and 182%. The 55–64 and 65–74 age groups increased in revision incidence during the study period, whereas 75–84 age group decreased in incidence. For rTKA, infection and aseptic loosening are the 2 most common modes of failure, whereas periprosthetic fracture and infection are most common for rTHA.

Conclusion—The incidence of rTHA/rTKA is projected to increase, particularly in young patients and for infection. Given the known risk factor profiles and advanced costs associated with revision arthroplasty, our projections should encourage institutions to generate revision-specific protocols to promote safe pathways for cost-effective care that is commensurate with current value-based health care trends.

Level of Evidence—IV.

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Keywords

revision hip arthroplasty; revision knee arthroplasty; incidence; projections; infection

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Primary hip and knee arthroplasty ranks among the top 5 most common procedures performed and among the top 5 fastest growing procedures each year, across all surgical disciplines in the United States [1]. Within orthopedics, hip and knee arthroplasty incidence far outpaces all other surgical procedures and thus routinely sits at the forefront of cost [2], value [3], outcome durability [4], and indications, [5] discussions, particularly in the eras of bundled payments [6], patient-reported outcomes [7], and quality-incentivized reimbursement [8,9]. The cost-effectiveness and quality of life benefits of total joint arthroplasty (TJA) are well documented and favor appropriately indicated surgery over nonoperative management [9–11].

Given the baseline high rate of success of modern TJA [12] and technological advances designed to extend the lifetime of primary implants [13–15], joint reconstruction that was once reserved for the low-demand population has been increasingly used in younger cohorts [16,17]. Varying reports of implant survivorship in higher demand patients range from nondifferent vs older patients [18,19] to significantly truncated [16,20]. Pragmatically, even modern implant bearings and well-fixed components have a finite life span that is more likely to be exceeded in the younger active patient.

As the more institutions adopt standardized processes for patient selection, preparation, surgical throughput, and expeditious discharge for primary total joint arthroplasty (pTJA), it is worth noting the dissimilarities between revision and primary arthroplasty. Relative to primary arthroplasty, revision surgeries have a higher rate of sepsis, prosthetic joint infection (PJI), medical complications, prolonged surgical time and length of inpatient stay, more blood loss and transfusion, nonhome discharge, and increased cost of care [21–24]. The advanced complexity of care for revision TJA (rTJA) patients calls into question the application of pTJA protocols to rTJA patients. As the incidence of rTJA continues to anecdotally rise, the importance of developing revision-specific protocols is self-evident in the efficacy of pTJA protocols [25]. Such protocols should be durable with time and thus should incorporate the projected rTJA demand to facilitate appropriate throughput capabilities. With the modern growth of primary arthroplasty, we expect an increase in the incidence of rTJA despite emphasis on pTJA survivorship. To examine this, we use statistical modeling to project long-term trends for rTJA to the year 2030. In addition, we analyze modern trends of indications and the epidemiology of revision hip and knee arthroplasty to the year 2030, based on the most recent, consecutive, and complete nationwide data, from 2002 to 2014.

Methods

Database Description

This study was exempt from institutional review board approval. Data were obtained from the national inpatient sample (NIS) database, which is maintained by the Agency for

Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project. This sample represents an approximation of 20% of all nonfederal hospitals in the United States. Weighting variables are assigned to the data to provide estimates, which can be applied to the entire country. Given the size and nationwide breadth of the NIS database, it is ideal for use in procedural epidemiologic investigations.

Inclusion Criteria and Variables

International Classification of Diseases, Ninth Revision, Clinical Modification procedure codes 00.80, 00.81, 00.82, 00.83, 00.84, 80.06, and 81.55 were used to identify all patients undergoing revision total knee arthroplasty (rTKA) and 00.70, 00.71, 00.72, 00.73, 70.05, and 81.53 for all revision total hip arthroplasty (rTHA) from 2002 to 2014 (Table 1). *International Classification of Diseases, Ninth Revision, Clinical Modification* diagnosis codes were used to identify the indication for each procedure (Table 1). The date range was chosen to account for the most recent complete data set, as the transition to International Classification of Diseases, Tenth Revision coding in the fourth quarter of 2015 introduces uncertainty into the data set and has the potential to confound the results. For subgroup analysis on the modes of failure of primary arthroplasty (indications for the studied revision), these data were first available in 2006, and so the study period was adjusted to 2006–2014 for this secondary analysis, and all patients with available diagnoses other than “not otherwise specified” were included for a more granular analysis.

Statistical Analysis

The annual incidence of rTJA procedures was obtained and subgrouped by age group (in decade increments: younger than 55 years, 55–64, 65–74, 75–84, and older than 85 years) and indications for revision, when available. Independent Poisson and linear regression models were used to project future incidence for rTHA and rTKAto2030, as done previously [26]. Furthermore, Poisson and linear models were also used to predict the future incidence of PJI for both rTHA and rTKA. Adjusted R^2 and pseudo-R^2 values were calculated for the linear and Poisson regression model to determine model fit. The linear model was chosen as a conservative reference to quantify the rate of growth within the study period. Poisson and linear regression analysis was performed using IBM SPSS (version 25.0; IBM Corp, Armonk, NY) and RStudio (version 1.2.133; RStudio, Inc., Vienna, Austria).

Results

Epidemiology

There were a total of 50,220 rTHAs performed in 2014, a 36% increase from the 36,898 performed in 2002. The age group with the greatest magnitude of change was 55–64 years, which grew by 184%; the 65–74 age group had the second largest growth with a 52% increase in the study period. The relative percentage of all revisions accounted for by the 55–64 age group increased by 9.1%, with 15.9% of all revisions in 2002 and 25% of revisions in 2014. The relative percentage increase for 65–74 age group was 2.9%, from 25.9% in 2002 to 28.8% in 2014. The younger than 55 and 75–84 age groups declined, whereas the older than 85 age group remained most unchanged (Table 2).

There were 72,100 rTKAs performed in 2014, a 102% increase from the 35,612 performed in 2002. The age groups with the largest change were, again, those aged 55–64 years (+195% change) and those aged 65–74 years (+119% change). The increase in the relative percentage of all revisions accounted for by the 55–64 age group was 8.6%, from 22.0% to 30.6%. For the 65–74 age group, the relative increase was 2.2%, from 31.1% to 33.3%. The 75–84 age group decreased, whereas younger than 55 and older than 85 age groups were relatively unchanged (Table 2).

Modes of Failure

From 2006 to 2014, the largest growth in causes of failure of primary total hip arthroplasty (pTHA) and indications for revision were periprosthetic fracture and PJI, with 74.7% and 65.0% increases, respectively. The relative percentage of indication for rTHA accounted for by periprosthetic fracture and PJI increased by 5.3% and 4.6%, respectively. Although aseptic loosening and prosthetic instability have remained the most common indications for revision at every time point of the study period, there was little change in overall incidence during the study period. Similarly, rarer indications for revision, osteolysis, and wear remained relatively stable in overall indigence. Implant failure declined in its incidence (Table 3).

From 2006 to 2014, the most common indications for revision of pTKA were aseptic loosening (+97.0% growth) and PJI (+53.4% growth). The relative percentage of indication for rTKA accounted for by loosening and PJI was 10.0% and 3.5%, respectively. Prosthetic instability also underwent significant growth, with a 91.8% increase in indications for revision but was less common in overall incidence than PJI or aseptic loosening at all time points. Again, implant breakage decreased substantially in incidence, whereas periprosthetic fracture, osteolysis, and bearing wear all underwent smaller decreases in incidence (Table 3).

Projections

The Poisson regression model predicted a 70% increase from 2014 in the incidence of rTHA to 85,528 (95% confidence interval [95% CI], 84,201–86,876; pseudo-R^2 = 0.865) procedures in 2030. Likewise, the linear model predicted a 43% increase from 2014 to 2030, to 71,384 procedures (95% CI, 65,241–78,426; R^2 = 0.852) (Fig. 1A). For rTKA, the Poisson model predicted an increase to 202,966 (95% CI, 200,251–205,717; pseudo-R^2 = 0.939) procedures from 2014 to 2030, a 182% increase. The linear model predicted a 78% increase to 127,984 (95% CI, 120,369–135,599; R^2 = 0.962) procedures from 2014 to 2030 (Fig. 1B).

Prediction models were also used to predict the rates of revisions secondary to PJI given their commonality of growth between both procedures. The Poisson model for rTHA predicts a 176% increase from 2014 to 2030, estimating 16,169 (95% CI, 15,392–16,985; pseudo-R^2 = 0.943) procedures. Likewise, the linear model saw an increase to 9830 (95% CI, 9291–10,370; R^2 = 0.969) procedures by 2030, a 68% increase from 2014 (Fig. 2A). PJI diagnoses for rTKA were projected by the Poisson model to increase 170% over 2014, to 53,569 (95% CI, 2,195–54,980; pseudo-R^2 = 0.933) procedures by 2030. The linear model predicted a 72% increase, 34,107 (95% CI, 32,206–36,009; R^2 = 0.966) procedures in 2030 over 2014 (Fig. 2B).

Discussion

Both rTHA and rTKA procedural volumes in the United States experienced substantial growth between 2002 and 2014, although the rate of growth for rTKA was nearly 3 times that of rTHA. Although our linear model represents conservative predictions, and the Poisson model incorporates exponential growth and signifies a more aggressive forecast, both models projected year-over-year growth in nationwide rTJA volume, based on a per-annum increase from 2002 to 2014, which raises the fear of uncontrolled growth of rTJA. These trends likely represent the summation of multiple forces. First, there is well-documented growth in the primary arthroplasty sector, which simply injects more potential revision candidates into the US population [27]. Furthermore, many of the problems that have plagued pTJA in the past have been addressed, as represented by our modes of failure subanalyses. For example, implant breakage has rapidly declined in incidence. Other modes of failure, such as bearing wear, osteolysis, and pTHA instability, remained relatively stable during our study period, despite the aforementioned growth in the pTJA sector [27], which is supported by their relative decrease in revisions accounted for during our study period. However, some problems remain unsolved despite extensive financial and academic investments. The growth of PJI during our study period reflects similar trends noted in other investigations [28–30]. Aseptic pTKA loosening also grew in incidence during our study period, as constraint and fixation method are continuously debated. Finally, as more pTJA are being performed, we have yet to make marked improvements in the long-term postoperative prevention of geriatric falls after pTJA; this inherent fact disproportionately affects THA in our study, as algorithmic approaches more commonly favor rTHA over open reduction and internal fixation, whereas fracture fixation is more commonly favored in fractured pTKA [31]. Our epidemiologic investigation and modeling offers the most modern insight into current trends of revision, which simultaneously identifies areas of need for further improvement of survivorship of pTJA and enables institutions to anticipate revision demand.

Although the overarching trends in the growth of rTHA and rTKA are noteworthy, subgroup analysis on modes of failure of pTJA reveal even more troublesome predictions. Despite perpetually growing interest in PJI prevention [32,33], even at a societal level [34], the 13 years of most recent data do not suggest any slowing of the incidence of revision for PJI. Rather, our models predict further growth by as much as 176% and 170% for THA and TKA, respectively, by 2030, supporting prior literature that suggests a losing battle against this devastating postoperative outcome [28,35]. However, the etiology of the continued increase of PJI as a mode of failure of pTJA also may be partially attributable to more standardized, sophisticated, and reliable means of diagnosis [36–41], whereas the gold standard for treatment remains under active investigation and debate [42]. Although unrestrained growth of all-cause rTJA is of concern, focal increase in revision for PJI poses major risk of accelerated growth in cost of care [43,44] and even patient morbidity, when compared with aseptic revisions [45–47]. Furthermore, the rTHA cohorts had a growth in revisions driven by periprosthetic fracture, which has a similarly disproportionate cost and morbidity detriment to the health care system and the patient [48,49]. Periprosthetic fractures are one of the most prominent drivers of readmission after index pTJA, which contributes to both the morbidity and resource utilization of the plague revisions for periprosthetic fracture [50].

Of additional worry, younger patients (aged 55–64) underwent the greatest increase in incidence of revision arthroplasty during the study period. As the survivorship profile of rTJA is far worse than that of pTJA [51,52], there is likely to be a growing population of multiply revised patients. pTJA remains one of the most successful surgical procedures in the United States. There is a nearly 96% all-cause survivorship at 15 years in pTKA [53], and approximately 82.3% of patients remain revision free at 25 years [54]. Similarly, approximately 77.8% of pTHA prostheses are still in situ at 25 years [55]. Furthermore, modern technology, such as ultraehigh molecular weight polyethylene [56,57], newer tibial polyethylene geometries [58], components design to impart prosthetic stability [59], additives such as vitamin E [60], and advancements in bearing surfaces [61–63], introduces many new variables to the primary arthroplasty survivorship equation. Yet, in concert with technological advances, approximately 20% of patients with pTHA are younger than 60 years old [17,64], and pTKA is projected to experience the largest growth in the younger than 55-year-old age group by 2030 [17,65], a population that is, in particular, at elevated risk of early failure [66]. As indications perpetually expand to a younger more active population, our findings support the notion that more patients are requiring revision surgery earlier in their lifetime. Unfortunately, even modern technology may not be sufficient in a young revision population to yield reliable outcomes in a high-demand population [67]. For example, early data have shown a significant decline in activity level and working status before and after revision joint arthroplasty: 95% and 93% of patients worked before rTHA and rTKA; only 33% and 7%, respectively, returned to work postoperatively [68]. As such, our findings of an increasingly young rTJA population are an alarming trend in this country.

Our findings shed light on the future demand for rTJA in the United States, and use of a large nationally representative database enables an externally valid prediction but carries notable limitations. However, the use of a database carries the inherent weaknesses of unverifiable accuracy of coding and data input. Furthermore, variables that potentially contribute to the likelihood of rTJA are excluded from the NIS database: implant choice [69], index case complexity [70], pertinent comorbidities (ie, chronic kidney disease) [71], included diseases' severity (ie, HbA1c) [72,73], and social determinants of health [74]. Such exclusions underscore the importance of a universal US arthroplasty registry that includes procedure-specific data and should aim to include contributions from high-volume tertiary specialty centers to rural community hospitals to most accurately portray current joint replacement trends. Furthermore, the distribution of revision arthroplasty incidence and data from 2002 to 2014 is heterogeneous and may not be perfectly described by classical statistical models because of relatively significant changes in care and resource utilization trends for both pTJA and rTJA [17,75–79]. Although we elected to use both a linear regression (assumes binomial distribution) and Poisson regression given its precedence in prior literature [80–82], it is plausible that neither model properly accounts for real-world variability as they do not define an upper limit of growth [83].

Conclusions

Although there are many factors that contribute to the demand for rTJA in the United States, projections of future need remain crucial. For example, our data demonstrate that by 2030, the incidence of rTKA may approach the volume of pTKA performed just 26 years ago, in 1993 [82]. In other words, revision arthroplasty, once considered a rare procedure, may grow in incidence to reach a recent nationwide procedural volume of primary replacement, one of the most commonly performed procedures across all surgical disciplines [1]. As such, our findings both advocate for the necessity of a national push toward anticipatory development of revision-specific perioperative pathways for these patients and estimate the actual throughput volumes such protocols may need to accommodate. Ignoring such trends and treating revision arthroplasty as an off-protocol procedure may miss a significant opportunity to decrease complications and improve outcomes through procedure-specific standardization of care [25,84–88]. Furthermore, early implementation of such protocols may also serve as disaster mitigation, in the event of another unexpected and unforeseen spike in revisions because of complications from newer hardware technology, akin to the development of adverse local tissue reactions and trunnion disease from metal-on-metal total hip arthroplasty [89–92], as such revisions for hardware complications have the potential for high resource and time utilization [92–94]. Furthermore, our data suggest uncontrolled growth in both revision for PJI and rTJA in a younger patient population, both of which have poorer outcomes than all-cause revision. These predictions isolate high-yield areas for further clinical investigation on limiting these morbid modes of failure, which could facilitate curtailed resource utilization and improved postrevision outcomes. Generally speaking, however, as high-volume centers, indications, and the patient pool continue to burgeon in pTJA, so will the need for all rTJAs; evidence-driven anticipation is the cornerstone of perpetual improvements in the management of arthroplasty patients in the revision setting.

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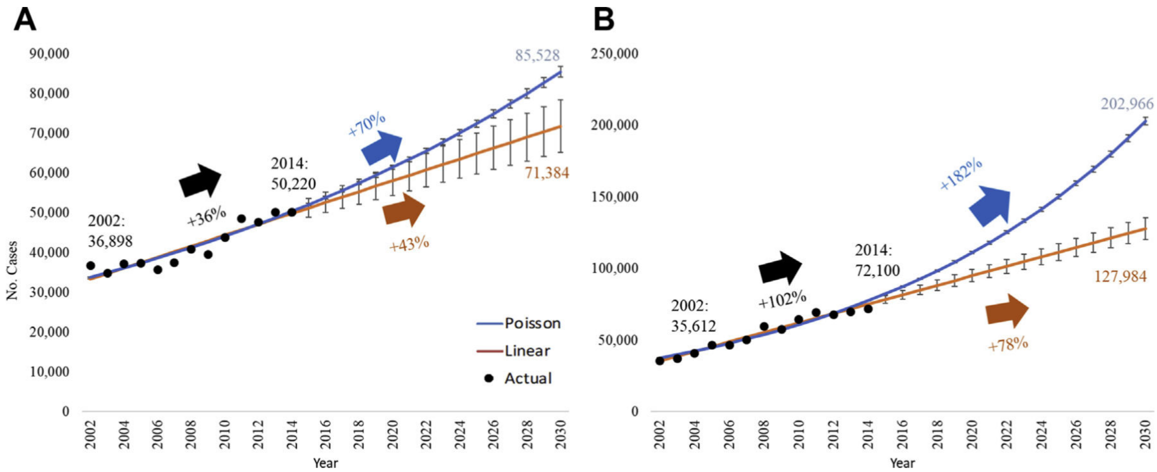

Fig. 1.

(A) Projections of revision total hip arthroplasty to 2030. (B) Projections of revision total knee arthroplasty to 2030. Error bars are 95% confidence interval.

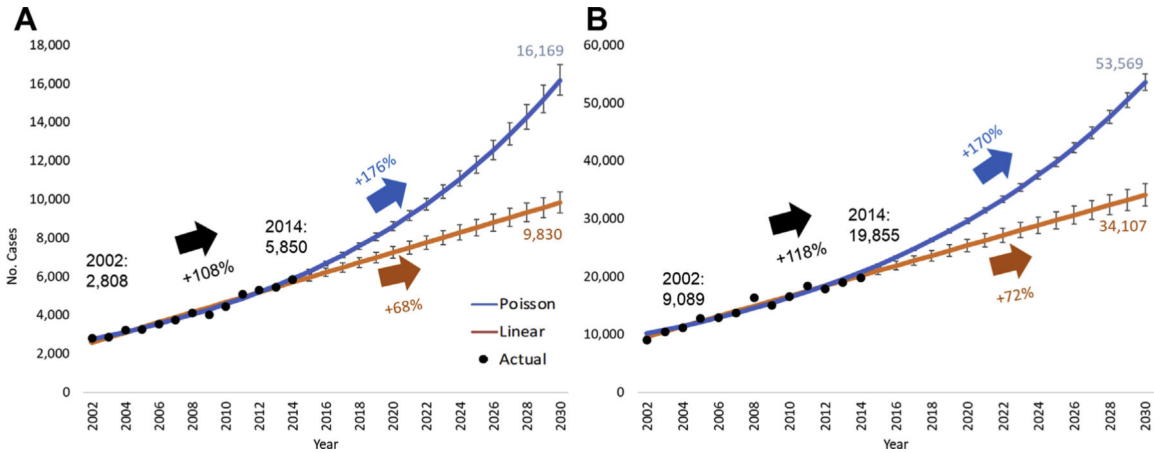

Fig 2.

(A) Projections of revision total hip arthroplasty for prosthetic joint infection to 2030. (B) Projections of revision total knee arthroplasty for prosthetic joint infection to 2030. Error bars are 95% confidence interval.

Table 1

International Classifications of Disease, Ninth Revision, Clinical Modification Codes for Revision Joint Arthroplasty.

Diagnosis Code	Description
996.41	Mechanical loosening of prosthetic joint
996.42	Dislocation of prosthetic joint
996.43	Prosthetic join implant failure/breakage
996.44	Periprosthetic fracture of prosthetic joint
996.45	Periprosthetic osteolysis of prosthetic joint
996.46	Articular bearing surface wear of prosthetic joint
996.47	Other mechanical complication of prosthetic joint
996.49	Other mechanical complication of internal orthopedic device, implant, and graft
996.66	Infection and inflammatory reaction because of internal joint prosthesis
84.56	Insertion of antibiotic cement spacer
84.57	Removal of antibiotic cement spacer

rTKA Procedure Codes	Description	rTHA Procedure Codes	Description
00.80	Revision of tibial, patellar, and femoral components	00.70	Revision of all components (both acetabular and femoral)
00.81	Revision of tibial component	00.71	Revision of acetabular component (includes femoral head)
00.82	Revision of femoral component	00.72	Revision of femoral component (includes acetabular liner)
00.83	Revision of patellar component	00.73	Isolated revision of head/liner
00.84	Isolated revision of tibial insert	80.05	Arthrotomy/removal of prosthesis
80.06	Arthrotomy/removal of prosthesis	81.53	Revision of knee, NOS
81.55	Revision of knee, NOS		

rTKA, revision total knee arthroplasty; rTHA, revision total hip arthroplasty; NOS, not otherwise specified.

Table 2

Revision by Age Group: Total Number and Percent of Total Accounted for.

Year	rTHA					rTKA				
	Number of Revisions									
	<55	**55–64**	**65–74**	**75–84**	**85+**	**<55**	**55–64**	**65–74**	**75–84**	**85+**
2002	8010	5881	9547	10,539	2917	5937	7870	11,060	9337	1402
2003	6902	5872	9137	10,081	2838	6258	8314	11,907	9273	1625
2004	7452	6588	9358	10,605	3258	7185	9546	12,784	9797	1687
2005	7306	6657	9125	11,094	3156	8649	11,293	14,074	10,663	1841
2006	7085	7184	8849	9611	3080	8233	12,418	14,073	10,250	1892
2007	7148	7241	9440	10,434	3319	8411	13,673	15,218	11,311	1998
2008	7832	8499	9614	10,996	4021	10,899	17,095	17,640	11,961	2395
2009	7039	8340	10,084	10,267	3922	9906	16,551	17,855	11,125	2258
2010	8382	9722	11,228	10,580	3923	11,709	19,154	19,190	12,272	2441
2011	9351	11,741	12,402	11,164	3993	12,268	21,473	20,803	12,405	2470
2012	8805	11,160	13,000	10,895	3880	12,090	20,460	20,980	12,315	2215
2013	8555	12,680	14,160	10,755	4015	11,305	21,450	22,640	12,070	2375
2014	8345	12,520	14,485	10,575	4285	11,570	22,045	23,960	11,995	2530
	Percentage (%) of Total Revisions Accounted for by Age Group									
2002	21.7	15.9	25.9	28.6	7.9	16.6	22.0	31.1	26.4	4.0
2014	16.7	25.0	28.8	21.0	8.5	16.0	30.6	33.3	16.6	3.5
Change	*−5.0*	**+9.1**	**+2.9**	*−7.6*	**+0.6**	*−0.6*	**+8.6**	**+2.2**	*−7.8*	*−0.5*

rTHA, revision total hip arthroplasty; rTKA, revision total knee arthroplasty. Bold values denotes growth in incidence; italicized values denotes decrease in incidence.

Table 3

Revision by Age Mode of Failure of Index Procedure: Total Number and Percent of Total Accounted for.

Year	rTHA							rTKA						
	Number of Revisions													
	PJI	**PPFx**	**IB**	**AS**	**O**	**I**	**BW**	**PJI**	**PPFx**	**IB**	**AS**	**O**	**I**	**BW**
2006	3545	3322	3507	6816	1516	7225	1112	12,946	685	4307	7012	771	2928	1641
2007	3764	3662	4105	7423	1716	7450	1311	13,699	877	4936	8179	866	3278	1705
2008	4112	4144	6210	6996	1623	8412	1033	16,334	1010	9051	9004	725	3977	1282
2009	4034	3795	4793	7405	1737	7556	1199	15,043	828	6546	10,279	738	3844	1547
2010	4443	4210	874	8953	2153	8179	1266	16,625	947	919	13,236	708	4211	1388
2011	5109	4801	971	8948	2209	8785	1331	18,359	895	995	13,304	906	5009	1529
2012	5310	4555	1045	8335	2330	8525	1675	17,925	930	830	13,270	820	5410	1360
2013	5460	5420	945	7975	2070	8920	1560	18,970	1095	865	13,560	690	5110	1285
2014	5850	5805	800	7925	2085	9220	1395	19,855	1070	795	13,815	625	5615	1190
	Percentage (%) of Total Revisions Accounted by Each Mode of Failure													
2006	13.1	12.3	13.0	25.2	5.6	26.7	4.1	42.7	2.3	14.2	23.2	2.6	9.7	5.4
2014	17.7	17.6	2.4	24.0	6.3	27.9	4.2	46.2	2.5	1.9	32.2	1.5	13.1	2.8
Change	**+4.6**	**+5.3**	*−10.6*	*−1.2*	**+0.7**	**+1.2**	**+0.1**	**+3.5**	**+0.2**	*−12.3*	**+10.0**	*−1.1*	**+3.4**	*−2.6*

rTHA, revision total hip arthroplasty; rTKA, revision total knee arthroplasty; PJI, prosthetic joint infection; PPFx, periprosthetic fracture; IB, implant breakage; AS, aseptic loosening; O, osteolysis; I, instability; BW, bearing wear. Bold values denotes growth in incidence; italicized values denotes decrease in incidence.