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Original Research

Temporal Trends in the Rate of Revision Total Knee Arthroplasty for Prosthetic Joint Infection

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ABSTRACT

Background: Perioperative practices have been introduced over the last decade to decrease the risk of periprosthetic joint infection (PJI). We sought to determine whether rates of revision total knee arthroplasty (TKA) for PJI decreased during the period 2006-2016.
Methods: This observational cohort study used data from the New York Statewide Planning and Research Cooperative System to identify patients undergoing TKA in 2006-2016. Data through 2017 were used to determine if patients underwent revision TKA for PJI (including debridement, antibiotics and implant retention) within 1 year of the primary surgery. A generalized estimating equation model, clustered by hospital, was used to examine the impact of time on likelihood of revision TKA for PJI.
Results: In 2006-2016, 233,165 primary TKAs performed were included. Mean age was 66.1 (standard deviation 10.3) years, and 65% were women. Overall, 0.5% of the patients underwent revision TKA for PJI within 1 year of surgery. The generalized estimating equation model showed that for primary TKA performed in 2006-2013, year of surgery did not impact the likelihood of revision TKA for PJI (odds ratio 1.00, 95% confidence interval 0.97-1.03, $P = .9221$), but that for primary TKA performed in 2014-2016, the likelihood decreased by year (odds ratio 0.76, 95% confidence interval 0.66-0.88, $P = .0002$).
Conclusions: The likelihood of revision TKA for PJI was stable from 2006 to 2013 but declined during the period 2014-2016 across patient and hospital categories. This decline could be due to infection mitigation strategies or other unmeasured factors.

Introduction

Periprosthetic joint infection (PJI) is a dreaded complication of total knee arthroplasty (TKA) that usually requires hospitalization for removal of the prosthesis and a prolonged course of antibiotics. [1] Almost half of PJI occur in the year after the primary TKA [2,3] and these PJI are linked both to patient and operating room factors. Rates of PJI rose in the early 2000s, a fact that was attributed to increasing comorbidities known to increase PJI risk in patients undergoing the procedure (eg, obesity or rheumatoid arthritis) [3-5]. Other risk factors for PJI included male sex, smoking, procedure duration, and hospital annual TKA volume [2,4]. Over the last decade, the increased recognition of modifiable PJI risk factors has led to approaches to mitigate that risk. These have been introduced in the operating room at many institutions and include routine use of perioperative antibiotic prophylaxis, laminar air

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flow purification systems, methicillin-resistant Staphylococcus aureus decolonization, surgical site antiseptic regimens, and use of tranexamic acid [6-13]. Additionally, optimization of patient-related factors such as diabetes control and smoking reduction or cessation has become widespread. The introduction of the Medicare Bundled Payments for Care Improvement (BPCI) initiative as a voluntary program 2013-2015 [14] could have incentivized uptake of these strategies. The goal of the current study was to examine the likelihood of revision TKA for PJI, including debridement, antibiotics and implant retention (DAIR), in patients who underwent their primary (original) TKA over the period 2006-2016. Our hypothesis was that rates of PJI declined at high-volume hospitals in the period after the introduction of Medicare's BPCI initiative.

Material and methods

We followed the STrengthening the Reporting of OBservational studies in Epidemiology guidelines for reporting observational cohort studies. The study was verified to be exempt by our institutional review board (#2016-166).

We used data from the New York Statewide Planning and Research Cooperative System for 2006-2017. The Statewide Planning and Research Cooperative System is an all-payer data reporting system that collects patient-level detail on patient characteristics, diagnoses and treatments, services, and charges for inpatient and outpatient services [15].

Participants

The cohort was defined as patients undergoing a primary TKA from 2006 to 2016. Diagnosis Related Group and International Classification of Diseases, Ninth and Tenth Revisions (ICD-9-CM Volume 3 or ICD-10-PCS) Procedure Codes (Supplemental Appendix Table 1) were used to identify patients having an eligible procedure. We excluded patients with a diagnosis code indicating a prior knee arthroplasty (ICD-9-CM Code V43.65, ICD-10-CM Z96.65%) to avoid incorrectly reporting the revision of a prior contralateral primary TKA

Table 1
Patient characteristics.

Variable	Overall		No septic TKR revision		Septic TKR revision		*P*-value
	N	(%)	N	(%)	N	(%)	
Age - mean (SD)	233,165	66.1 (10.3)	231,933	66.1 (10.1)	1232	63.7 (11.1)	<.001
Sex (female)	151,094	(64.8)	150,496	(64.9)	598	(48.5)	<.001
Race							.030
White	178,285	(76.5)	177,351	(76.5)	934	(75.8)	
Black	24,113	(10.3)	23,970	(10.3)	143	(11.6)	
Other	30,767	(13.2)	30,612	(13.2)	155	(12.58)	
Ethnicity (Hispanic)	18,186	(7.8)	18,096	(7.8)	90	(7.3)	.601
Insurance							
Medicaid (any)[a]	27,036	(11.6)	26,861	(11.6)	175	14.2	.004
Medicaid (primary)[b]	13,709	(5.9)	13,611	(5.9)	98	(8.0)	<.001
Medicare	121,036	(51.9)	120,461	(51.9)	575	(46.7)	
Other	6439	(2.8)	6405	(2.8)	34	(2.8)	
Private	81,002	(34.7)	80,553	(34.7)	449	(36.4)	
Work Compensation	10,979	(4.7)	10,903	(4.7)	76	(6.2)	
Charlson comorbidity							<.001
0	133,783	(57.4)	133,179	(57.4)	604	(49.0)	
1	67,918	(29.1)	67,514	(29.1)	404	(32.8)	
2+	31,464	(13.5)	31,240	(13.5)	224	(18.2)	
Comorbidities							
Diabetes	49,329	(21.2)	49,032	(21.1)	297	(24.1)	.011
Obesity	54,794	(23.5)	54,474	(23.5)	320	(26.0)	.040
Renal disease	8422	(3.6)	8369	(3.6)	53	(4.3)	.193
COPD	3283	(1.4)	3253	(1.4)	30	(2.4)	.002
Osteonecrosis	1184	(0.5)	1171	(0.5)	13	(1.1)	.007
Inflammatory arthritis	7888	(3.4)	7833	(3.4)	55	(4.5)	.035
Surgical complication	1120	(0.5)	1106	(0.5)	14	(1.1)	<.001
Hospital TKR volume							<.001
≤89	21,088	(9.0)	20,946	(9.0)	142	(11.5)	
90-235	52,464	(22.5)	52,165	(22.5)	299	(24.3)	
236-644	85,419	(36.6)	84,966	(36.6)	453	(36.8)	
≥645	74,194	(31.8)	73,856	(31.8)	338	(27.4)	
Hospital location							.405
Small town/rural	7950	(3.4)	7909	(3.4)	41	(3.3)	
Micropolitan	11,158	(4.8)	11,109	(4.8)	49	(4.0)	
Metropolitan	213,997	(91.8)	212,856	(91.8)	1141	(92.7)	
TKR discharge, year							<.001
2006	19,413	(8.3)	19,303	(8.3)	110	(8.9)	
2007	18,935	(8.1)	18,816	(8.1)	119	(9.7)	
2008	19,074	(8.2)	18,970	(8.2)	104	(8.4)	
2009	19,429	(8.3)	19,320	(8.3)	109	(8.9)	
2010	21,161	(9.1)	21,029	(9.1)	132	(10.7)	
2011	20,880	(9.0)	20,770	(9.0)	110	(8.9)	
2012	21,333	(9.2)	21,216	(9.2)	117	(9.5)	
2013	21,878	(9.4)	21,736	(9.4)	142	(11.5)	
2014	22,525	(9.7)	22,409	(9.7)	116	(9.4)	
2015	23,767	(10.2)	23,670	(10.2)	97	(7.9)	
2016	24,770	(10.6)	24,694	(10.7)	76	(6.2)	

COPD, chronic obstructive pulmonary disease; TKR, total knee replacement; SD, standard deviation.
[a] Medicaid as any source of payment (primary or secondary).
[b] Medicaid as principal reimbursement.

because ICD-9-CM procedure codes do not specify laterality. We also excluded out-of-state residents because subsequent treatment obtained in their home state would not be captured within the database.

A total of 233,165 patients with primary TKA performed from 2006 to 2016 were included in the analysis. Mean age was 66.1 (standard deviation 10.3) years, 64.8% were women, 10.3% were Black and 42.6% had a Charlson comorbidity score >0 (Table 1). Medicaid was the primary or secondary insurance for 11.6%, and 4.7% had workers compensation insurance. Nine percent of primary TKAs were performed at hospitals, performing <89 TKA per year.

The study outcome was revision TKA for PJI within 1 year of primary TKA, including DAIR, compared to patients having no revision or revision for another indication. We chose 1 year because almost half of PJI occurs during the year after the primary TKA [2,3] and PJI during the first year is more likely to be due to operative factors than in later years, when infections generally arise from hematogenous seeding of the prosthesis. Diagnosis Related Group and ICD-9-CM and ICD-10-PCS Procedure Codes were used to identify patients who underwent revision TKA (Supplemental Appendix Table 2). The reason for revision TKA was determined using ICD-9-CM and ICD-10-CM diagnosis codes and categorized as septic or not septic (eg, fracture, mechanical ["aseptic"], or other) (Supplemental Appendix Table 3). Patients were excluded if they underwent sequential TKA (ie, had TKA of both knees during separate admissions) because the laterality of revision TKA is not available from ICD-9-CM procedure codes.

Variables

We included covariates that have been linked to revision TKA for PJI risk in the literature [2,16] including age, sex, insurance, comorbidities (diabetes, obesity, renal disease, chronic obstructive pulmonary disease), joint-specific diagnoses (osteoarthritis, osteonecrosis, rheumatoid arthritis, psoriatic arthritis, spondyloarthropathy), surgical complications during the primary TKA (hemorrhage, wound disruption, retained foreign body), and hospital annual TKA volume. Patient comorbidities, indication for surgery, and surgical site complications during the primary TKA were determined using ICD-9-CM and ICD-10-CM diagnosis codes (Supplemental Appendix Table 4). Hospital location (rural, micropolitan, or metropolitan) was determined based on the hospital zip code [17]. Hospital TKA volume was calculated as the number of TKA admissions during the discharge year of the patient's primary TKA and categorized as reported by Wilson et al [18].

Statistical analyses

Continuous variables were summarized as mean ± standard deviation and compared using t-tests. Categorical variables were summarized as frequency (percent) and compared using chi-squared tests. We calculated rates of revision TKA for PJI by year of primary surgery and visualized the data using bar graphs. After noting a decline in the rate of revision TKA for PJI in patients who underwent TKA after 2013, we performed a generalized estimating equation (GEE) model clustered by facility to further analyze our findings. The effect of time on the likelihood of revision TKA for PJI was evaluated by including variables for the year of primary TKA, a time cutpoint variable (0 if TKA performed from 2006-2013 and 1 if TKA performed from 2014-2016), and an interaction term between the year of surgery and the time cutpoint variable.

Results

Of the 233,165 patients, 1232 (0.5%) underwent revision TKA for PJI within 1 year of their primary TKA. Factors associated with revision TKA for PJI in univariable analysis included younger age, male sex, having a Charlson comorbidity score >0, inflammatory arthritis, having a surgical complication during the primary TKA admission, Medicaid insurance, surgery at a low TKA volume hospital, and year that the primary TKA surgery was performed (Table 1). Utilization of TKA increased during the study period, 2006-2016 (Table 1).

As shown in Figure 1, the rate of revision TKA for PJI declined after 2013. The average rate was 0.6% in the period 2006-2013, compared to 0.4% in the period 2014-2016. This decline was seen across patient characteristics associated with revision TKA for PJI, including sex, age, comorbidity burden, and Medicaid insurance (Fig. 2) and across hospital TKA volume categories (Fig. 3).

A GEE model clustered by hospital showed that year of surgery was not associated with the likelihood of revision TKA for PJI for primary TKA performed in 2006-2013 (odds ratio [OR] 1.00, 95% confidence interval [CI] 0.97-1.03, $P = .9221$), while the likelihood decreased by year for primary TKA performed in 2014-2016 (OR 0.76, 95% CI 0.66-0.88, $P = .0002$ (Table 2). Comparison of patient characteristics for primary TKA performed in 2006-2013 and 2014-2016 showed small statistical differences in patient characteristics that did not appear clinically relevant (Table 3).

Undergoing primary TKA at a very low TKA volume hospital (<89/year) was associated with a higher rate of revision TKA for PJI (OR 1.54, 95% CI 1.11-2.15; $P = .01$) compared to very high-volume hospitals (≥ 645/year) in the GEE model (Table 2) and a higher percentage of TKAs were performed at very high-volume hospitals during the period 2014-2016 compared to 2006-2013 (41% vs 28%, $P < .001$) (Table 3).

Discussion

In this observational cohort study, we demonstrate that 0.5% of TKA patients had a revision TKA (explantation or DAIR) for PJI within 1 year of their surgery during the period 2006-2016. While rates of revision TKA for PJI remained relatively stable for TKA performed in 2006-2013, they declined significantly for TKA performed in 2014-2016. This decline was similar across patient categories and hospitals.

Although we cannot determine from our study why rates of revision TKA for infection declined starting in 2014, it is notable that the BPCI initiative was phased in as a voluntary program precisely during the period 2013-2015. Although the mandatory comprehensive Care for Joint Replacement (CJR) program was not introduced until 2016 [19], pilot programs were created in many

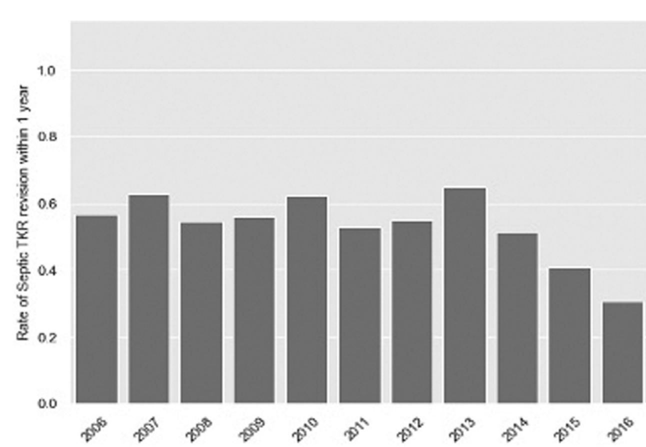

Figure 1. Rate of revision of total knee arthroplasty for prosthetic joint infection within 1 year of the primary total knee replacement. TKR, total knee replacement.

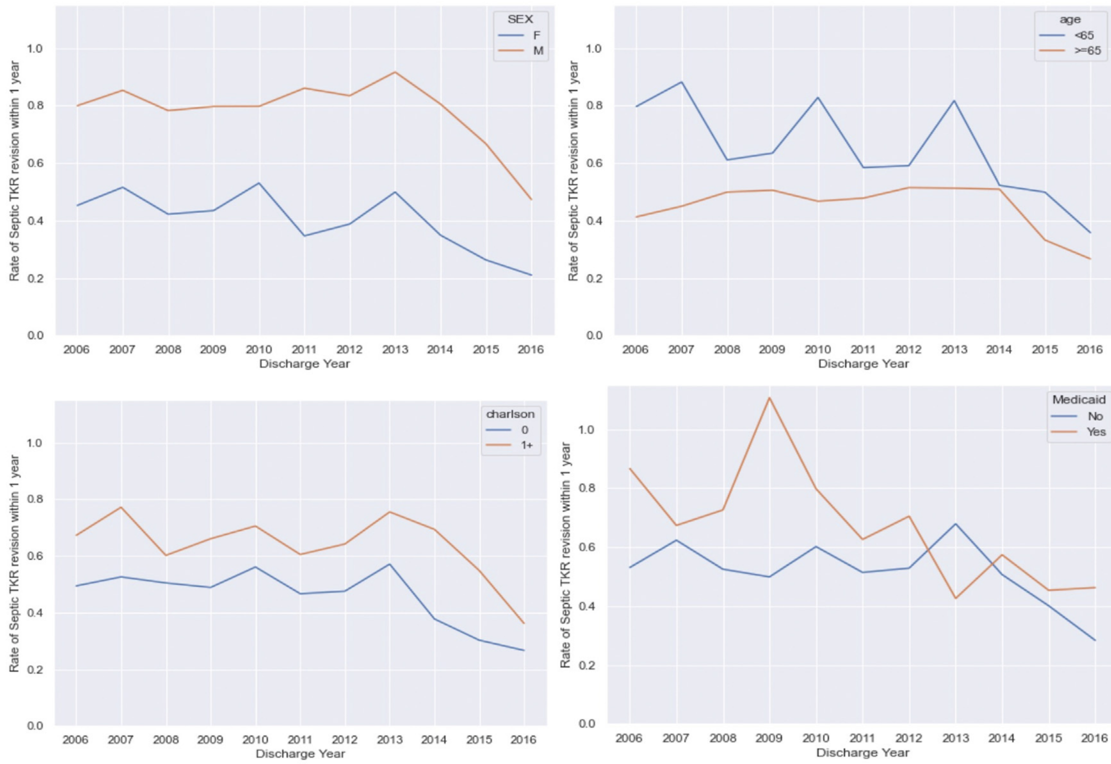

Figure 2. Rate of revision of total knee arthroplasty for prosthetic joint infection within patient subgroups over time. TKR, total knee replacement.

institutions in the run up to its implementation. Participation in both the voluntary BPCI program and the mandatory CJR bundle was very high in the greater New York City metropolitan area [20], where almost half of New York State's population resides [21]. Under bundled payments, health care organizations are paid for all related services during an episode of care (up to 90 days after discharge). While this can, in theory, incentivize hospital to "cherry pick" patients for surgery who have fewer comorbidities, we did not observe clinically important differences in the prevalence of comorbidities in patients who underwent surgery in 2006-2013 compared to 2014-2016. Bundled payments can also serve as an incentive to minimize surgical complications in positive ways. Examples, with regard to PJI prevention, include patient health optimization strategies, body mass index cutoffs for surgery, increased

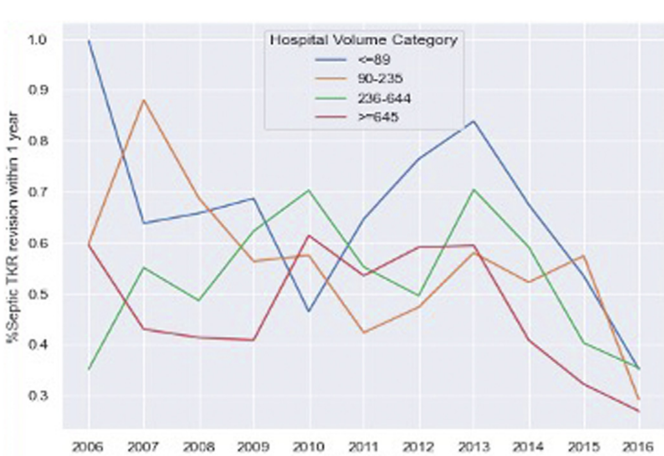

Figure 3. Rate of revision of total knee arthroplasty for prosthetic joint infection within hospital TKA volume categories over time. TKR, total knee replacement.

Table 2
Generalized estimating equation, with clustering by hospital, to identify variables associated with septic revision TKR.

Variable	Odds ratio	Lower CI	Upper CI	*P*-value
Age	0.97	0.97	0.98	<.0001
Sex (male)	2.00	1.78	2.24	<.0001
Race				
Black	1.02	0.82	1.26	.8803
Asian	0.43	0.20	0.92	.0305
Unknown	1.02	0.74	1.41	.8929
Ethnicity (Hispanic)	0.83	0.60	1.17	.2879
Insurance				
Medicaid	1.09	0.86	1.37	.4761
Other	0.86	0.57	1.29	.4605
Private	0.84	0.73	0.98	.0237
Workers' compensation	0.86	0.67	1.10	.2274
Comorbidities				
Charlson comorbidity index 1	1.37	1.20	1.57	<.0001
Charlson comorbidity index 2+	1.68	1.37	2.06	<.0001
Diabetes	0.87	0.75	1.02	.0889
Obesity	1.20	1.06	1.35	.0027
Renal disease	0.94	0.71	1.24	.6635
COPD	1.74	1.24	2.45	.0013
Osteonecrosis	1.86	1.07	3.23	.0287
Inflammatory arthritis	1.15	0.87	1.51	.3315
Surgical complications	2.10	1.25	3.56	.0054
Hospital TKR volume (ref $\geq$ 645)				
$\leq$89	1.54101	1.11	2.15	.0104
>89, $\leq$235	1.27469	0.94	1.72	.1155
>235, $\leq$644	1.17292	0.88	1.56	.2728
Hospital location				
Small town/rural	0.84451	0.54	1.33	.4656
Micropolitan	0.63733	0.43	0.95	.0264
Year of primary TKA	0.99847	0.97	1.03	.9221
Cutpoint: [2006-2013] vs [2014-2016]	1.13871	0.84	1.55	.4089
Interaction year*cutpoint	0.76072	0.66	0.88	.0002

COPD, chronic obstructive pulmonary disease; TKR, total knee replacement.
The asterisk is the symbol chosen to represent the interaction between year and cutpoint.

Table 3
Patient characteristics 2006-2013 and 2014-2016.

Variable	Overall		2006-2013		2014-2016		*P*-value
	N	%	N	%	N	%	
Age, mean (SD)	233,165	66.1 (10.3)	162,103	66.3 (10.5)	71,062	65.7 (10.0)	<.001
Sex							
F	151,094	64.80	105,858	65.30	45,236	63.66	<.0001
Race							
White	178,285	76.46	125,837	77.63	52,448	73.81	<.0001
Black	24,113	10.34	16,249	10.02	7864	11.07	
Asian	3698	1.59	2243	1.38	1455	2.05	
Other	27,069	11.61	17,774	10.96	9295	13.08	
Ethnicity							
Hispanic	18,186	7.80	12,365	7.63	5821	8.19	<.0001
Medicaid							
(any)	27,036	11.60	17,695	10.92	9341	13.14	<.0001
Payer							
Medicaid	13,709	5.88	8170	5.04	5539	7.79	<.0001
Medicare	121,036	51.91	85,646	52.83	35,390	49.80	
Other	6439	2.76	4009	2.47	2430	3.42	
Private	81,002	34.74	56,779	35.03	24,223	34.09	
Work compensation	10,979	4.71	7499	4.63	3480	4.90	
Charlson comorbidity index							
0	133,783	57.38	93,245	57.52	40,538	57.05	<.0001
1	67,918	29.13	47,685	29.42	20,233	28.47	
2+	31,464	13.49	21,173	13.06	10,291	14.48	
Diabetes	49,329	21.16	34,402	21.22	14,927	21.01	.2382
Obesity	54,794	23.50	30,542	18.84	24,252	34.13	<.0001
Renal disease	8422	3.61	5016	3.09	3406	4.79	<.0001
COPD	3283	1.41	1140	0.70	2143	3.02	<.0001
Osteonecrosis	1184	0.51	879	0.54	305	0.43	.0004
Inflammatory arthritis	7888	3.38	5431	3.35	2457	3.46	.1875
Surgical complications	1120	0.48	849	0.52	271	0.38	<.0001
Hospital volume							
≤89	21,088	9.04	16,693	10.30	4395	6.18	<.0001
90-235	52,464	22.50	39,811	24.56	12,653	17.81	
236-644	85,419	36.63	60,298	37.20	25,121	35.35	
≥645	74,194	31.82	45,301	27.95	28,893	40.66	
Urban/rural							
Small town/rural	7950	3.41	5833	3.60	2117	2.98	<.0001
Micropolitan	11,158	4.79	8133	5.02	3025	4.26	
Metropolitan	213,997	91.80	148,077	91.38	65,920	92.76	

COPD, chronic obstructive pulmonary disease; SD, standard deviation.

use of antiseptics, screening and decolonization of nasal staphylococcus carriage, the use of preoperative topical antiseptics, clippers rather than razors for hair removal, laminar air flow in the operating room, a reduction in blood transfusions, and increased use of tranexamic acid [6,7]. There is ample evidence supporting the benefits of many of these approaches in preventing surgical site infections (eg, antiseptics, clippers) [10] and PJI (eg, nasal decolonization, tranexamic acid) [11,12], although the benefits of others (eg, laminar air flow) [13] have been more difficult to demonstrate.

During the period 2006-2016, utilization of TKA increased. Therefore, our finding that the percentage of total knee replacement performed at very high-volume hospitals in 2014-2016 was higher than during the period 2006-2013 is not surprising. This is because our definition of high volume and low volume was numerically fixed (≥645 TKA per year vs <89 per year), rather than representing a percentile of volume. However, because having surgery at a very high-volume hospital was in fact associated with a lower rate of TKA for PJI, at least in comparison to very low-volume hospitals, the growing contribution of these hospitals to the total pool of TKA performed may explain some of the positive trends seen after 2013, though not the cutpoint noted after 2013. In point of fact, the decline in the rate of revision TKA for PJI occurred across all hospital TKA volume categories, and in our GEE model, there was a strong association between the time cutpoint (2006-2013 vs 2014-2016) and the risk of revision TKA for PJI even after controlling for hospital volume category and multiple other covariates. Thus, our analysis shows that rates of PJI declined at high-volume hospitals in the period after the introduction of Medicare's BPCI initiative; however, similar declines were also seen across the hospital spectrum.

Risk factors for revision TKA for PJI identified in our study are similar to those demonstrated in other studies [2,4,22]. A recent study demonstrated that during the period 2005-2014, there was a gradual increase in utilization of DAIR, rather than removal of the prosthesis, to manage PJI occurring in the first 90 days after primary TKA or total hip arthroplasty [23]. We demonstrate that the overall rate of revision TKA for PJI did not change during that time period, even though management strategies (DAIR vs explantation) may have.

A strength of our study is its large size. A limitation is that we did not have access to implant types, and constrained condylar prostheses have been shown to be a risk factor for revision TKA for PJI [22]. In addition, all patients in this study came from New York State, which could impact generalizability. This study analyzes data from 2006-2016 (plus an additional year of follow-up), and future studies will be needed to determine whether trends hold.

Conclusions

Rates of revision TKA for PJI declined in the years 2014-2016. This could be due to infection mitigation strategies introduced in pilot programs at high TKA-volume hospitals in New York in anticipation of the Medicare comprehensive CJR bundle or other factors. Further studies are needed to confirm that these trends persist and whether they are generalizable to other geographic areas in the United States.

Conflicts of interest

A. R. Bass receives all support from the Stavros Niarchos Foundation Complex Joint Reconstruction Center: Faith and Peter Linden Orthopedic Research Initiative and is the Treasurer of the American College of Rheumatology. A. V. Carli is a consultant for Heraeus Medical. H. T. Do receives all support from the Stavros Niarchos Foundation Complex Joint Reconstruction Center: Faith and Peter Linden Orthopedic Research Initiative. S. M. Goodman receives research support from Arthritis Foundation, Novartis, and NIH; is the chair of the ACR Guidelines Subcommittee; and participates on UCB's advisory board. P. K. Sculco is a consultant for Intellijoint Surgical, Zimer Biomet, and ATEC. M. P. Figgie has stock in HS2 and WishBone, is a consultant for Lima and WishBone, receives royalties from Lima and WishBone, and is the Board of Directors of WishBone. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101442.

CRediT authorship contribution statement

Anne R. Bass: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Bella Mehta:** Writing – review & editing, Methodology, Formal analysis. **Peter K. Sculco:** Writing – review & editing, Formal analysis, Conceptualization. **Yi Zhang:** Methodology, Formal analysis, Data curation, Writing – review & editing. **Huong T. Do:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing. **Katharine Kayla J. Glaser:** Data curation, Writing – review & editing. **Carlos Aude:** Data curation, Writing – review & editing. **Alberto V. Carli:** Writing – review & editing, Conceptualization. **Mark P. Figgie:** Conceptualization, Writing – review & editing. **Susan M. Goodman:** Conceptualization, Formal analysis, Methodology, Writing – review & editing.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.artd.2024.101442.

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