Association of Type and Frequency of Postsurgery Care with Revision Surgery after Total Joint Replacement

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ABSTRACT

Context: Postmarket surveillance is limited in the ability to detect medical device problems. Electronic health records can provide real-time information that might help with device surveillance. Specifically, the frequency of postsurgery care might indicate early problems and determine high-risk patients requiring more active surveillance.

Objective: To evaluate whether intensity of postsurgery care is associated with revision risk after total joint arthroplasty (TJA).

Design: Using an integrated health care system's TJA registry, we identified primary TJA performed between April 2001 and July 2013 (22,953 knees and 9904 hips). Survival analyses evaluated the frequency of specific types of outpatient and inpatient utilization 0 to 90 and 91 to 180 days postoperatively and revision risk.

Main Outcome Measures: Revision surgery occurring at least 6 months after primary TJA.

Results: Knee arthroplasty recipients with 3 or more outpatient orthopedic allied health/nurse visits within 90 days had a 2.2 times (95% confidence interval [CI] = 1.6-2.9) higher risk of revision within the first 2 years postoperatively and 10.1 times higher risk (95% CI = 7.6-13.3) after 2 years. Compared with hip arthroplasty recipients who had 0 to 3 visits, patients with 6 or more outpatient orthopedic office visits within 90 days had a 15.7 times (95% CI = 5.7-42.9) higher risk of revision. Similar results were observed for 91-day to 180-day visits.

Conclusion: Future studies are needed to determine if more specific data on reasons for the higher frequency of outpatient visits can refine these findings and elicit more specific recommendations for TJA devices.

INTRODUCTION

More than 600 orthopedic implantable medical devices are approved by the US Food and Drug Administration (FDA) for use each year.[1,2] Most total joint arthroplasty (TJA) devices are released into the market through the 510(k) process, which typically relies on the substantial equivalence of the device to an existing approved medical device or predicate.[3] As a result, new devices can be approved on the basis of "substantial equivalence" as opposed to safety and effectiveness. The Depuy ASR hip replacement recall (DepuySynthes, Warsaw, IN)[4,5] demonstrates the potential impact of devices approved on the basis of being substantially equivalent as opposed to new clinical evidence of safety and effectiveness. A minority of devices are evaluated through the FDA Pre-Market Approval process.[6] However, clinical data are not routinely required, and those applications requiring a clinical trial are often limited because of strict patient inclusion and exclusion criteria, limited surgeon and center exposure, and lack of longitudinal follow-up. The FDA uses a number of postmarket tools to continue monitoring medical devices, including passive adverse event reporting, mandated postapproval studies, and postmarket surveillance studies.[7] These, too, have limited value in detection of medical device problems.[8] Recognizing the need for more evidence of medical device performance for evaluation of safety and effectiveness and for decision making, the FDA has spearheaded the development of the National Evaluation System for health Technology (NEST) and promoted the use of real-world evidence from registries and other electronic health information collected as part of routine clinical care.[9,10] Part of this includes efficient and coordinated collection of robust data using existing infrastructure to promote medical device safety, effectiveness, and quality.[9,10]

National TJA registries provide a method for postmarket surveillance using real-world data and have played a critical role in the detection of medical device failures such as the ASR.[11] Still, owing to the lag that can occur with data capture and validation, registries are better suited for evaluation of long-term outcomes rather than contemporary surveillance. Instead, the electronic health record (EHR) has been proposed as a tool for public health surveillance.[12] The EHR can provide a wide range of real-time electronic health information, which might also allow for more timely surveillance of failures after TJA.

An EHR has the capability of collecting patient health care utilization information, including postsurgical care. Identification of postoperative service utilization is a potentially new area of early identification of TJA failures. The frequency of postsurgery care might be an indicator of early problems after the procedure that could be used as a real-time proxy indicator to help screen high-risk patients who require more active surveillance. Therefore, in a proof-of-concept study, we sought to determine whether the intensity of postsurgery care, as identified through inpatient and outpatient visits during the first 6-month postoperative period, is associated with a higher risk of TJA revision surgery.

METHODS

Study Design, Data Sources, and Study Sample

A cohort study was conducted using Kaiser Permanente's (KP) Total Joint Replacement Registry (TJRR). KP covers 12.3 million patients in 8 geographical Regions,[13] and all TJA procedures

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performed in this system are captured by the TJRR. The registry data collection and data quality procedures have been previously discussed.[14,15] To summarize briefly, the TJRR collects intraoperative information on patients undergoing total hip arthroplasty (THA) and total knee arthroplasty (TKA) using paper and electronic forms completed by the operating surgeon. This information is supplemented with data from several other sources, including the institution's EHR, administrative claims data, membership information (containing membership attrition because of end of health care coverage or death), a diabetes registry, and other institutional databases (eg, Geographically Enriched Member Sociodemographics). Revision procedures are prospectively monitored using validated algorithms, which are then validated through manual chart review by a trained research associate. Data on subsequent health care utilization for TJA recipients were obtained from the health care system's EHR (Epic, Epic Systems, Verona, WI).[16]

All primary TJA recipients registered from April 2001 to July 2013 were included in the sample. Patients with postoperative complications (ie, surgical site infection, deep vein thrombosis, and pulmonary embolism) or revisions within 6 months after the primary procedure were excluded. The final sample included cases from 232 surgeons at 16 hospitals in Southern California. This study was approved by the institutional review board before its commencement.

Exposure of Interest

Frequency and type of postsurgery care in the health care system during the first 6 months after the TJA was the exposure of interest in this study. There are 2 main categories of utilization recorded in the integrated health care system's EHR: Outpatient and inpatient-related admissions and visits. Outpatient utilization occurs outside the hospital, whereas inhospital (inpatient) utilization was hospital related. Eight specific types of outpatient care tracked by the EHR were evaluated: Office visit, orthopedic allied health/nurse visit, orthopedic office visit, family practice visit, internal medicine visit, urgent care, occupational medicine/physical therapy, and hospital encounter. Orthopedic office visits are scheduled with orthopedic specialty practitioners, whereas office visits are with nonorthopedic specialty practitioners such as family medicine, primary care, and pain management. Nine specific types of inpatient care tracked by the EHR were evaluated, including hospital admission with surgery, hospital ambulatory surgery, charge router-automated hospital accounting records, Emergency Department (ED) visit, home health, inpatient, observation, outpatient procedure, and outpatient in the hospital. Information about inpatient utilization was first introduced to the registry data collection algorithm in late 2005, then reached full coverage in late 2006; to minimize selection bias and the impact of missing data, inpatient postsurgery care evaluation included primary TJA performed from January 2007 onward. To determine whether the timing of postsurgery care was also important to detect early failures, we evaluated utilization within 1 to 90 days and 91 to 180 days postoperative separately.

The frequency of postsurgical care was first evaluated as intervals of varying length determined by sample quintiles and histograms of their frequencies. For each postsurgery care type, the decision to evaluate the variable categorically or continuously was based on log-likelihood ratio test, convergence of the model, and proportional hazards property in a crude Cox proportional hazards model. For TKA, categorical variables were chosen for office visits and orthopedic allied health/nurse visits, with the categories of 0 to 2 and 3 or more; for occupational medicine/physical therapy visits, 0 to 3 and 4 or more; hospital encounter and urgent care, yes or no; family practice visits, 0 to 1 and 2 or more; internal medicine visits, 0 to 1, 2 to 3, and 4 or more. The remaining postsurgery care types were evaluated as continuous variables.

For THA, categorical variables were chosen for office visits and orthopedic office visits, and the categories used were 0 to 3, 4 to 5, and 6 or more; for occupational medicine/physical therapy, 0 to 2, 3 to 8, and 9 or more; hospital encounter, urgent care, internal medicine visits, ED visits, and inpatient, yes or no; family practice visits, 0 to 2, 3 to 6, and 7 or more; and orthopedic allied health/nurse visits, 0 to 2 and 3 or more. The remaining postsurgery care types were evaluated as continuous variables. For categorical variables, the reference level was the interval that included 0.

Outcome of Interest

Revision surgery occurring at least 6 months after the primary TJA was the outcome of interest in this study. Revisions occurring before 6 months (180 days) were excluded. Revision was defined as any reoperation after the index procedure in which an implant was exchanged. Revision operations were prospectively captured and adjudicated by the TJRR.

Covariates

Patient covariates included in our analyses were sex (men vs women), age (≥ 55 vs < 55 years), race (white vs other),

Table 1. Characteristics of patients undergoing primary total joint arthroplasty for encounter analysis, 2001-2013[a]

	Knee replacement			Hip replacement		
Characteristic	Total (N = 22,953)	Not revised (n = 22,460)	Revised (n = 493)	Total (N = 9904)	Not revised (n = 9771)	Revised (n = 133)
Men	8348 (36.4)	8159 (36.3)	189 (38.3)	4073 (41.1)	4031 (41.3)	42 (31.6)
Age ≥ 55 y	20,979 (91.4)	20,595 (91.7)	384 (77.9)	8269 (83.5)	8170 (83.6)	99 (74.4)
White race	13,603 (59.3)	13,320 (59.3)	283 (57.4)	6925 (69.9)	6821 (69.8)	104 (78.2)
Body mass index, kg/m²						
< 30	10,130 (44.1)	9935 (44.2)	195 (39.6)	5839 (59.0)	5755 (58.9)	84 (63.2)
30-34	7035 (30.6)	6871 (30.6)	164 (33.3)	2497 (25.2)	2466 (25.2)	31 (23.3)
≥ 35	5676 (24.7)	5543 (24.7)	133 (27.0)	1522 (15.4)	1505 (15.4)	17 (12.8)

[a] Data are number (%). Missing data are as follows: Knee: Race (n = 102, 0.4%), body mass index (n = 112, 0.5%); Hip: Race (n = 41, 0.4%), body mass index (n = 46, 0.5%).

body mass index (BMI, 30-34 or ≥ 35 vs < 30 kg/m^2), and comorbidities. Diabetes was identified by linking the TJRR to the KP diabetes registry; all other comorbidities were identified using the Elixhauser Comorbidity Index.[17]

Statistical Analysis

All analyses were procedure specific (THA and TKA). Means, standard deviations, frequencies, medians, and interquartile ranges were used to describe the study sample. Cox proportional hazards models were used to evaluate the association between different postsurgical care types and revision after the primary procedure. Proportional hazards assumptions were tested using log(-log) curves and a Kolmogorov-Smirnov test. If proportional hazards assumptions were not met, a time-dependent covariate created by an interaction between a predictor and a function of the study time was included in the model. All models adjusted for covariates. Hazard ratios (HR) and 95% confidence intervals (CI) are presented, as are p values according to the Wald χ^2 test. Follow-up time was defined as the difference between the primary TJA date and the date of the revision, membership termination from the integrated health care system, death, or the end date of the study period (December 31, 2013), whichever came first. Patients with membership termination or death were censored from our analysis using their date of last follow-up. An α of 0.05 was used as the threshold for statistical significance for individual tests. Postsurgery care data were analyzed using R version 3.1.2 software (R Foundation).

RESULTS

There were 22,953 TKA and 9904 THA procedures conducted during our study timeframe (Table 1). The TKA cohort consisted of 8348 men (36.4%); 20,979 patients (91.4%) were age 55 years or older; 13,603 (59.3%) were white; and 10,130 (44.1%) had a BMI less than 30 kg/m^2. The crude overall incidence of revision after TKA during the study period was 2.1% (n = 493). The THA cohort consisted of 4073 men (41.1%), 8269 patients (83.5%) were age 55 years or older, 6925 (69.9%) were white, and 5839 (59.0%) had a BMI less than 30 kg/m^2. The crude incidence of revision was 1.3% (n = 133) in the THA recipients.

The 4 most frequent outpatient utilization types after TKA were orthopedic office visit, occupational medicine/physical therapy, office visit, and family practice visit in the first 180 postoperative days. Orthopedic office visit, office visit, and family practice visit were the most common outpatient utilization after THA. Table 2 provides details of outpatient

Table 2. Number of outpatient encounters by total joint arthroplasty postoperative time period and revision status, April 2001 to July 2013

	Quarter 1 (1-90 d)						Quarter 2 (91-180 d)					
Encounter type[a]	Number (%)	Total visits	Median (IQR)[b]	Number (%)	Total visits	Median (IQR)[b]	Number (%)	Total visits	Median (IQR)[b]	Number (%)	Total visits	Median (IQR)[b]
Knee	Not revised (n = 22,460)			Revised (n = 493)			Not revised (n = 22,460)			Revised (n = 493)		
Family practice	16,399 (73.0)	126,480	3 (0-8)	404 (81.9)	5526	8 (2-16)	11,610 (51.7)	30,984	1 (0-2)	326 (66.1)	1359	2 (0-4)
Hospital encounter	7114 (31.7)	10,128	0 (0-1)	231 (46.9)	409	0 (0-1)	3957 (17.6)	5427	0 (0-0)	162 (32.9)	288	0 (0-1)
Internal medicine	11,856 (52.8)	71,156	1 (0-4)	309 (62.7)	2,731	1 (0-7)	7491 (33.4)	17,375	0 (0-1)	199 (40.4)	658	0 (0-2)
Occupational M/T, PT	19,797 (88.1)	306,033	10 (4-18)	480 (97.4)	13,562	19 (8-39)	9695 (43.2)	55,437	0 (0-3)	312 (63.3)	2995	2 (0-9)
Office visit	18,928 (84.3)	94,008	3 (1-6)	472 (95.7)	4218	7 (4-12)	18,512 (82.4)	83,662	3 (1-5)	473 (95.9)	3738	6 (3-10)
Orthopedic AH/ NV/OV	9554 (42.5)	28,190	0 (0-2)	273 (55.4)	1079	2 (0-3)	7003 (31.2)	13,328	0 (0-1)	238 (48.3)	628	0 (0-2)
Orthopedics, medicine	22,403 (99.7)	181,951	6 (4-10)	493 (100.0)	9164	16 (11-23)	16,932 (75.4)	39,307	1 (1-2)	473 (95.9)	2030	3 (2-5)
Urgent care	6119 (27.2)	12,750	0 (0-1)	204 (41.4)	578	0 (0-2)	2091 (9.3)	2805	0 (0-0)	83 (16.8)	119	0 (0-0)
Hip	Not revised (n = 9771)			Revised (n = 133)			Not revised (n = 9771)			Revised (n = 133)		
Family practice	6984 (71.5)	50,755	3 (0-7)	6984 (71.5)	1268	5 (1-14)	107 (80.5)	12,402	0 (0-2)	4828 (49.4)	323	1 (0-3)
Hospital encounter	2966 (30.4)	4219	0 (0-1)	70 (52.6)	153	1 (0-2)	1646 (16.8)	2317	0 (0-0)	50 (37.6)	110	0 (0-1)
Internal medicine	4987 (51.0)	28,454	1 (0-4)	4987 (51.0)	889	2 (0-8)	95 (71.4)	7162	0 (0-1)	3116 (31.9)	218	0 (0-2)
Occupational M/T, PT	5756 (58.9)	54,550	2 (0-7)	5756 (58.9)	1433	5 (0-12)	98 (73.7)	11,344	0 (0-1)	2631 (26.9)	386	0 (0-3)
Office visit	8173 (83.6)	38,243	3 (1-5)	122 (91.7)	973	7 (3-11)	7854 (80.4)	34,238	2 (1-5)	121 (91.0)	942	5 (3-10)
Orthopedic AH/ NV/OV	4232 (43.3)	11,519	0 (0-2)	4232 (43.3)	332	2 (0-4)	93 (69.9)	5178	0 (0-1)	2845 (29.1)	167	1 (0-2)
Orthopedics, medicine	9732 (99.6)	71,807	6 (3-9)	9732 (99.6)	2184	14 (10-21)	133 (100.0)	15,461	1 (0-2)	6850 (70.1)	511	3 (2-5)
Urgent care	2451 (25.1)	5012	0 (0-1)	2451 (25.1)	144	0 (0-1)	54 (40.6)	1156	0 (0-0)	851 (8.7)	37	0 (0-0)

[a] Encounter types were specified by our integrated health care system's electronic health record (Epic, Epic Systems, Verona, WI).
[b] Expressed as median and interquartile range of total visits per patient for the encounter of interest.
AH = allied health; IQR = interquartile range; M/T = medicine/therapy; NV = nurse visit; OV = office visit; PT = physical therapy.

utilization per postoperative timeframe. The 4 most common types of inpatient (hospital-related) utilization for both THA and TKA were outpatient in the hospital, ED visit, charge router-automated hospital accounting record, and inpatient (Table 3).

For TKA, a greater frequency of outpatient utilization in both days 1 to 90 and 91 to 180 intervals were associated with higher revision surgery after adjusting for age, sex, race, and BMI (Table 4). Specifically, during postoperative days 1 to 90, patients with at least 2 family practice visits were 1.8 times (95% CI = 1.5-2.3) more likely to experience a revision surgery than those who had 0 or 1 visit. Patients with any hospital encounter had 2.1 times (95% CI = 1.6-2.7) higher risk of revision in the first 5 years after the index procedure, and 5.0 times (95% CI = 2.8-8.7) higher risk of revision thereafter. Compared with those with 0 or 1 internal medicine visit, patients with at least 4 visits were 1.6 times (95% CI = 1.3-2.0) more likely to experience revision surgery. Patients with at least 4 occupational medicine/physical therapy visits were 3.0 times (95% CI = 2.2-4.0) more likely to experience a revision surgery than those with 0 to 3 visits. Compared with those with 0 to 2 office visits, patients with at least 3 visits were 4.7 times (95% CI = 3.6-6.2) more likely to experience a revision surgery. Patients with at least 3 orthopedic allied health/nurse visits had a 2.2 times (95% CI = 1.6-2.9) higher risk of revision in the first 2.1 postoperative years and 10.1 times (95% CI = 7.6-13.3) higher risk thereafter compared with those with 0 to 2 visits. For every 1 additional orthopedic office visit, there was a 10% higher risk of revision surgery (HR = 1.1, 95% CI = 1.1-1.1). Finally, patients who received any urgent care had a 2.1 times (95% CI = 1.7-2.6) higher risk of revision than patients who did not. Similar results were found for the second postoperative quarter (Table 4). No associations between inpatient utilization and revision surgery were observed for TKA.

For THA, we also found significant associations between postoperative outpatient utilization types and revision surgery, adjusting for age, sex, race, and BMI (Table 5). Patients with at least 7 family practice visits had a 2.6 times (95% CI = 1.7-4.0) higher risk of revision compared with those who had 0 to 2 visits. Patients who had any hospital encounter in the first postoperative quarter were 3.1 times (95% CI = 2.2-4.4) more likely to experience a revision surgery, and those who had any internal medicine visit in the same period were 2.7 times (95% CI = 1.8-4.1) more likely to experience a revision surgery. Compared with those who had 0 to 2 occupational medicine/

Table 3. Number of inpatient encounters by total joint arthroplasty postoperative time period and revision status, Janurary 2007 to July 2013[a]

	Quarter 1 (1-90 d)						Quarter 2 (91-180 d)					
Encounter type[b]	Number (%)	Total visits	Median (IQR)[c]	Number (%)	Total visits	Median (IQR)[c]	Number (%)	Total visits	Median (IQR)[c]	Number (%)	Total visits	Median (IQR)[c]
Knee	Not revised (n = 17,953)			Revised (n = 319)			Not revised (n = 17,953)			Revised (n = 319)		
Admit with surgery	1 (0)	1	0 (0-0)	0 (0)	0	0 (0-0)	0 (0)	0	0 (0-0)	1 (0.3)	1	0 (0-0)
Charge router-auto HAR	2245 (12.5)	4151	0 (0-0)	31 (9.7)	40	0 (0-0)	1669 (9.3)	3075	0 (0-0)	28 (8.8)	36	0 (0-0)
Emergency Department	3520 (19.6)	5479	0 (0-0)	68 (21.3)	100	0 (0-0)	1352 (7.5)	2304	0 (0-0)	26 (8.2)	35	0 (0-0)
Home health	115 (0.6)	164	0 (0-0)	0 (0)	0	0 (0-0)	6 (0)	27	0 (0-0)	0 (0)	0	0 (0-0)
Hospital ambulatory surgery	381 (2.1)	545	0 (0-0)	6 (1.9)	9	0 (0-0)	538 (3.0)	755	0 (0-0)	24 (7.5)	28	0 (0-0)
Inpatient	1495 (8.3)	2475	0 (0-0)	26 (8.2)	28	0 (0-0)	1564 (8.7)	2357	0 (0-0)	21 (6.6)	25	0 (0-0)
Observation	370 (2.1)	514	0 (0-0)	5 (1.6)	5	0 (0-0)	223 (1.2)	301	0 (0-0)	1 (0.3)	1	0 (0-0)
Outpatient procedure	127 (0.7)	186	0 (0-0)	1 (0.3)	1	0 (0-0)	309 (1.7)	443	0 (0-0)	4 (1.3)	5	0 (0-0)
Outpatient in hospital	5515 (30.7)	11,175	0 (0-1)	95 (29.8)	149	0 (0-1)	5003 (27.9)	10,410	0 (0-1)	100 (31.3)	183	0 (0-1)
Hip	Not revised (n = 7736)			Revised (n = 90)			Not revised (n = 7736)			Revised (n = 90)		
Admit with surgery	2 (0)	2	0 (0-0)	0 (0)	0	0 (0-0)	0 (0)	0	0 (0-0)	0 (0)	0	0 (0-0)
Charge router-auto HAR	1027 (13.3)	1699	0 (0-0)	6 (6.7)	6	0 (0-0)	750 (9.7)	1310	0 (0-0)	4 (4.4)	9	0 (0-0)
Emergency Department	1509 (19.5)	2166	0 (0-0)	27 (30.0)	59	0 (0-1)	614 (7.9)	1095	0 (0-0)	12 (13.3)	25	0 (0-0)
Home health	50 (0.6)	65	0 (0-0)	0 (0)	0	0 (0-0)	3 (0)	6	0 (0-0)	0 (0)	0	0 (0-0)
Hospital ambulatory surgery	82 (1.1)	111	0 (0-0)	1 (1.1)	4	0 (0-0)	189 (2.4)	256	0 (0-0)	0 (0)	0	0 (0-0)
Inpatient	597 (7.7)	847	0 (0-0)	3 (3.3)	4	0 (0-0)	750 (9.7)	1125	0 (0-0)	11 (12.2)	22	0 (0-0)
Observation	146 (1.9)	167	0 (0-0)	2 (2.2)	2	0 (0-0)	94 (1.2)	112	0 (0-0)	1 (1.1)	1	0 (0-0)
Outpatient procedure	30 (0.4)	39	0 (0-0)	1 (1.1)	1	0 (0-0)	91 (1.2)	122	0 (0-0)	1 (1.1)	1	0 (0-0)
Outpatient in hospital	2496 (32.3)	4549	0 (0-1)	28 (31.1)	38	0 (0-1)	2235 (28.9)	4313	0 (0-1)	24 (26.7)	50	0 (0-1)

[a] Hospital encounter information available from Janurary 2007 onward.
[b] Encounter types were specified by our integrated health care system's electronic health record (Epic, Verona, Wisconsin, USA)
[c] Expressed as the median and interquartile range of total visits per patient for the encounter of interest.
Auto HAR = automated hospital accounting records; IQR = interquartile range.

physical therapy visits, patients had a 1.7 times (95% CI = 1.1-2.6) and 2.5 times (95% CI = 1.6-3.8) higher risk of revision when they had 3 to 8 visits and at least 9 visits in the first postoperative quarter, respectively. During the same first postoperative quarter, patients with at least 6 office visits had a 4.1 times (95% CI = 2.8-6.2) higher risk of revision compared with those who had 0 to 3 visits. Patients who had at least 3 orthopedic allied health/nurse visits were more likely to experience a revision surgery, with a 5.0 times (95% CI = 3.1-8.1) risk in the first 3.5 postoperative years and a 10.4 times (95% CI = 5.7-18.7) risk thereafter. Patients with at least 6 orthopedic office visits had a 15.7 times (95% CI = 5.7-42.9) higher risk of revision compared with those who had 0 to 3 visits. Patients who received any urgent care had a 2.4 times (95% CI = 1.6-3.6) higher risk of revision than patients who did not have urgent care. Similar results were found for the second postoperative quarter. Revision surgery was also associated with any ED utilization in the first postoperative quarter (HR = 1.9, 95% CI = 1.2-3.0) but not in the second postoperative quarter (HR = 1.8, 95% CI = 1.0-3.5).

DISCUSSION

Using a TJA population from a large integrated health care system, we found postsurgical care to be associated with risk of revision surgery after primary TJA. A higher frequency of outpatient care utilization was associated with revision risk for TJA recipients, but thresholds were different for TKA and THA. Three or more orthopedic allied health/nurse visits throughout the first 180 days postoperatively had the strongest association with revision risk after TKA. Meanwhile, 6 or more orthopedic office visits in the first 90 days and 3 or more orthopedic allied health/nurse visits in the 91-day to 180-day window had the strongest associations after THA. The THA recipients with more emergency (inpatient) care utilization were also at higher risk of revision.

To our knowledge, this is the first study to use the EHR to evaluate postsurgical care and revision risk after TJA. Our study lacks granular clinical details of specific reasons for the encounters. Furthermore, planned visits were not discerned from unplanned visits—patient initiated or surgeon directed—nor whether visits were related or unrelated to the primary procedure. Our purpose was to determine whether the intensity of postsurgical care was associated with revision risk, regardless of the nature of the care. This is the most general information available that can be readily extracted from the EHR, allowing for expedited screening and intervention for patients who might be at higher risk of failure.

Table 4. Adjusted models for associations of outpatient encounters and revision (181 days after surgery) of total knee arthroplasty recipients[a]

Encounter type	Visit level	Cumulative revision rate, quarter 1[b] 2 y	4 y	6 y	Adjusted multivariable model, quarter 1[b] HR (95% CI)	p value	Cumulative revision rate, quarter 2[b] 2 y	4 y	6 y	Adjusted multivariable model, quarter 2[b] HR (95% CI)	p value
Family practice	0-1	0.9	1.5	2.1	Reference		1.0	1.5	2.2	Reference	
	≥ 2	1.5	2.5	3.6	1.8 (1.5-2.3)	< 0.001	1.9	3.4	4.9	2.3 (1.9-2.8)	< 0.001
Hospital encounter[c]	No	1.1	1.7	2.2	Reference		1.0	1.7	2.4	Reference	
	Yes	1.7	3.2	5.2	2.1 (1.6-2.7)	< 0.001	2.6	4.3	6.3	2.6 (2.2-3.2)	< 0.001
					5.0 (2.8-8.7)	< 0.001					
Internal medicine	0-1	1.1	1.9	2.7	Reference		1.1	1.9	2.7	Reference	
	2-3	1.5	2.2	2.8	1.3 (0.9-1.7)	0.120	1.4	2.5	3.7	1.5 (1.1-1.9)	0.004
	≥ 4	1.6	2.6	3.8	1.6 (1.3-2.0)	< 0.001	2.9	4.8	7.1	2.9 (2.2-3.8)	< 0.001
Occupational M/T, PT	0-3	0.6	0.9	1.3	Reference		0.9	1.6	2.2	Reference	
	≥ 4	1.5	2.5	3.6	3.0 (2.2-4.0)	< 0.001	2.4	4.2	6.0	2.6 (2.1-3.1)	< 0.001
Office visit	0-2	0.4	0.7	1.0	Reference		0.4	0.7	1.2	Reference	
	≥ 3	1.7	2.9	4.1	4.7 (3.6-6.2)	< 0.001	1.9	3.3	4.6	4.4 (3.5-5.7)	< 0.001
Orthopedic AH/NV/OV[d]	0-2	1.1	1.7	2.2	Reference		1.1	1.9	2.6	Reference	
	≥ 3	2.1	6.5	13.1	2.2 (1.6-2.9)	< 0.001	3.9	8.7	16.4	4.6 (3.6-5.9)	< 0.001
					10.1 (7.6-13.3)						
Orthopedics, medicine	0-3	0.0	0.1	0.1	—		0.7	1.3	1.9	—	
	≥ 4	1.6	2.7	3.8	1.1 (1.1-1.1) per 1 increment	< 0.001	4.8	7.7	10.3	1.2 (1.1-1.2) per 1 increment	< 0.001
Urgent care	No	1.1	1.7	2.4	Reference		1.2	2.0	2.8	Reference	
	Yes	1.8	3.4	4.8	2.1 (1.7-2.6)	< 0.001	2.3	4.0	5.2	2.0 (1.6-2.6)	< 0.001

[a] No significant associations were observed for inpatient encounters and risk of revision in patients undergoing total knee replacement. Encounter types were specified by our integrated health care system's electronic health record (Epic, Epic Systems, Verona, WI). Multivariable models were adjusted for age, sex, race, and body mass index; 0.5% of data (n = 112) were excluded in the model because of missing data in covariates.
[b] Quarter 1 was 1-90 d; quarter 2 was 91-180 d.
[c] Stratification for time dependence; effect of "yes" visits within and after 5 years postoperatively compared with no visits.
[d] Stratification for time dependence; effect of ≥ 3 visits within and after 2 years postoperatively compared with 0-2 visits.
AH = allied health; CI = confidence interval; HR = hazard ratio; M/T = medicine/therapy; NV = nurse visit; OV = office visit; PT = physical therapy.

Inacio et al[18] reported on health care utilization after anterior cruciate ligament reconstruction and found an increased number of orthopedic office visits within the first 90 days postoperatively to be associated with revision surgery, similar to our THA findings. This study hypothesized that the higher frequency of orthopedic office visits was an indication of short-term clinical failure.[18] A number of studies have also used the EHR to evaluate postoperative opioid use, finding a higher number of medications to be associated with arthroplasty revision risk.[19-21]

The FDA recognizes the current limitations of postmarket surveillance and the need for a more rigorous system in the US; a national strategy for medical device evaluation using real-world evidence from existing electronic data sources and clinical registries has been proposed.[22] Although the need for surveillance is recognized, the rising volume of TJA challenges the ability to postoperatively monitor large populations of patients. Patient-reported outcome measures, and simpler patient-questionnaire evaluations, may identify early patients at risk of failure,[23] but time and labor costs are prohibitive. In contrast, frequency and type of postsurgery care utilization can readily be identified using existing data sources and may potentially be a novel indicator for orthopedic surgeons to monitor patients at higher risk of failure after TJA. Surveillance and early detection of failures is critical for patient safety and quality. Readmissions are used as a standard indicator for safety and quality nationally[24]; however, with the exception of certain planned inpatient readmissions (eg, dialysis, scheduled operative procedures), TJA recipients are not expected to be hospitalized after the procedure. More studies are emphasizing the importance of additional types of postsurgical care, such as ED visits, in the measurement of quality after TJA.[25-29] The EHR is capable of collecting all patient contacts in the health care system, not just limited to utilization related to the surgical procedure. The encounter types identified here might be a possible early indicator for health care practitioners in the identification of high-risk patients who require more active surveillance. Health care organizations with a comprehensive EHR may have

Table 5. Adjusted models for associations of outpatient/inpatient encounters and revision (181 days after surgery) of total hip arthroplasty recipients[a]

Encounter type	Visit level	Cumulative revision rate, quarter 1[b] 2 y	4 y	6 y	Adjusted multivariable model, quarter 1[b] HR (95% CI)	p value	Cumulative revision rate, quarter 2[b] 2 y	4 y	6 y	Adjusted multivariable model, quarter 2[b] HR (95% CI)	p value
Outpatient encounters (N = 9858)											
Family practice	0-2	0.5	0.9	1.6	Reference		0.5	1.0	1.7	Reference	
	3-6	0.4	0.7	1.3	0.9 (0.5-1.5)	0.659	0.9	1.9	3.3	1.9 (1.2-2.9)	0.004
	≥ 7	1.2	2.3	3.6	2.6 (1.7-4.0)	< 0.001	3.1	4.7	6.8	4.6 (2.4-8.6)	< 0.001
Hospital encounter	No	0.4	0.8	1.3	Reference		0.5	1.0	1.5	Reference	
	Yes	1.2	2.3	4.1	3.1 (2.2-4.4)	< 0.001	1.4	2.6	5.3	3.8 (2.6-5.5)	< 0.001
Internal medicine	No	0.4	0.8	1.1	Reference		0.6	1.0	1.5	Reference	
	Yes	0.9	1.6	2.9	2.7 (1.8-4.1)	< 0.001	0.9	1.7	3.2	2.3 (1.6-3.3)	< 0.001
Occupational M/T, PT	0-2	0.5	0.9	1.3	Reference		0.6	1.1	1.7	Reference	
	3-8	0.8	1.5	2.2	1.7 (1.1-2.6)	0.026	1.0	2.3	3.6	1.9 (1.2-3.1)	0.006
	≥ 9	1.0	1.9	3.9	2.5 (1.6-3.8)	< 0.001	1.3	2.3	6.8	3.0 (1.6-5.5)	< 0.001
Office visit	0-3	0.4	0.7	1.1	Reference		0.4	0.7	1.0	Reference	
	4-5	0.3	0.6	0.9	0.8 (0.4-1.5)	0.408	0.6	1.1	2.4	1.8 (1.1-3.1)	0.027
	≥ 6	1.4	2.6	4.8	4.1 (2.8-6.2)	< 0.001	1.6	2.8	4.7	4.3 (2.9-6.4)	< 0.001
Orthopedic AH/NV/OV[c]	0-2	0.5	0.9	1.3	Reference		0.6	1.1	1.8	Reference	
	≥ 3	1.4	5.0	11.5	5.0 (3.1-8.1)	< 0.001	1.4	5.5	17.6	3.3 (1.7-6.5)	< 0.001
					10.4 (5.7-18.7)	< 0.001				21.7 (9.9-47.3)	< 0.001
Orthopedics, medicine	0-3	0.1	0.1	0.3	Reference		0.4	0.7	1.2	Reference	
	4-5	0.2	0.3	0.3	1.5 (0.4-5.7)	0.536	1.9	3.7	6.1	5.1 (3.3-8.0)	< 0.001
	≥ 6	1.2	2.2	3.7	15.7 (5.7-42.9)	< 0.001	2.9	6.6	11.2	8.8 (5.6-13.9)	< 0.001
Urgent care	No	0.5	1.0	1.5	Reference		0.6	1.1	1.9	Reference	
	Yes	1.3	2.1	3.7	2.4 (1.6-3.6)	< 0.001	1.5	2.4	4.1	2.1 (1.3-3.4)	0.004
Inpatient encounters (N = 7825)											
Emergency Department	No	0.5	1.1	2.0	Reference		0.6	1.1	2.0	Reference	
	Yes	1.3	2.0	2.4	1.9 (1.2-3.0)	0.009	1.1	2.3	3.1	1.8 (1.0-3.5)	0.060

[a] Encounter types were specified by our integrated health care system's electronic health record (Epic, Epic Systems, Verona, WI). Multivariable models were adjusted for age, sex, race, and body mass index; 0.5% of data (n = 47) were excluded in the model because of missing data in covariates.
[b] Quarter 1 was 1-90 d; quarter 2 was 91-180 d.
[c] Stratification for time dependence; effect of "≥ 3" visits within and after 3.5 years postoperatively compared with no visits.
AH = allied health; CI = confidence interval; HR = hazard ratio; M/T = medicine/therapy; NV = nurse visit; OV = office visit; PT = physical therapy.

an alternative method to monitor large populations of TJA recipients. Although revisions caused by implant failure mostly showed up after 6 months, early detection through inpatient and outpatient encounters was warranted even in the early latent period, as found in this study.

Our study is not without limitations. First, our objective was to determine whether any postsurgery care was associated with a higher risk of revision surgery, not to create a prediction model for revision. Our intent was not to identify specific devices at higher risk of revision caused by certain modes of failure, but rather a proof of concept to determine whether readily extractable information from the EHR could be used to screen patients at higher risk of revision who may require more active surveillance. Future studies are needed to determine whether this information can be used for surveillance of high-risk medical devices. Second, there is also potential for missing data or misclassified encounter types, along with the other inherent limitations of using EHR data. Third, our study excluded patients with complications or revisions within the first 6 months of the primary procedure, which were mostly caused by infections and fractures of the bone. Although our study findings may not be applied to short-term failures, we believe these findings may be useful as a safety indicator for later failures after the primary procedure. Finally, because we were limited to the health care utilization types available through the current EHR platform (Epic), these results may not be generalizable to other institutions using different EHR platforms.

Study strengths included the patient population in the integrated health care system from which the sample was obtained, which is socioeconomically and demographically representative of the geographical regions it covers.[30,31] Our study included a cohort of patients with validated outcomes through a total joint replacement registry and full postsurgical care information from our system's EHR.

CONCLUSION

Using postsurgical care identified through the EHR, we found increased outpatient care utilization to be associated with revision surgery after TJA, although the thresholds for revision risk differed between TKA and THA. Health care practitioners might benefit from more active surveillance and intervention for patients with a higher frequency of these types of postsurgical care. Future investigations should determine if more specific data on reasons for seeking postsurgical care can help refine these findings and whether this type of EHR information can be used in prospective surveillance for high-risk medical devices. ❖

Disclosure Statement

The author(s) have no conflicts of interest to disclose.

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