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ORIGINAL ARTICLE

Incidence and risk factors for periprosthetic joint infection: A common data model analysis

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ABSTRACT

Objectives: The aim of this study was to determine the incidence of periprosthetic joint infection (PJI) following primary total joint arthroplasty (TJA) and to investigate risk factors in a large cohort utilizing common data model (CDM).

Patients and methods: The entire cohort of primary and revision hip or knee TJA between January 2003 and December 2017 was retrospectively analyzed utilizing the CDM database. We detected patients who had revision TJA as a consequence of PJI. We determined the incidence of PJI and examined risk factors, including demographic features, comorbidities, prior corticosteroid usage, and preoperative laboratory values.

Results: There were 34 revision TJAs as a consequence of PJI (hip, 16; knee, 18) among 12,320 primary TJAs (hip, 4,758; knee 7,562), representing 0.27% incidence of PJI (hip, 0.33%; knee 0.23%). Of the patients, 15 were males and 19 were females. The mean age at the time of primary TJA was 59.8±17.5 (range, 31 to 85) years in hip PJI patients and 71.4±7.2 (range, 56 to 80) years in knee PJI patients. Hypertension and urinary tract infection were both associated with PJI following primary hip TJA. Age between 70 and 79 years, male sex, urinary tract infection, anemia, and prior corticosteroid usage were all associated with PJI following primary knee TJA.

Conclusion: This study indicates the viability of employing CDM to undertake research on PJI and serves as a reference for future CDM-based risk factor analysis. Preoperative screening and mitigating identified risk factors can aid in the reduction of PJI following TJA.

Keywords: Incidence, infection, prosthesis-related, risk factors, total joint replacement.

Total joint arthroplasty (TJA) is a popular orthopedic operation that can significantly enhance the quality of life for individuals suffered from severe arthritis. Over the past two decades, the amount of TJAs has expanded rapidly.[1] However, the most serious complication of TJA, periprosthetic joint infection (PJI), may result in severe joint dysfunction, as well as an increased risk of mortality. Numerous studies have been conducted to identify risk factors for PJI, encompassing hypertension (HTN), diabetes mellitus, hyperlipidemia, kidney disease, rheumatoid arthritis, anemia, depressive disorder, urinary tract infection (UTI), male sex, elderly, being overweight, tobacco use, prior corticosteroid usage, blood transfusion, longer surgical time, wound complication, and poor nutritional support.[2-17] However, only a limited number of them included numerous risk factors.[3,5-10,12-16] Additionally, several studies have shown contradictory findings regarding the same risk factors.[12-16,18]

Previous studies to identify risk factors for PJI following TJA used electronic medical record (EMR) or administrative claims databases.[3-6,8-10,14,16,19] While EMR systems provide detailed and specific

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information about a patient's clinical status, it takes considerable time and effort to identify a large number of cases. Additionally, the inconsistent and heterogeneous data formats utilized by various EMR systems across institutions complicate large-scale clinical research collaboration. On the other hand, while observational studies based on administrative claim databases are capable of analyzing vast quantities of data from multiple regions or nations, obtaining and handling relevant clinical data for specific analysis is not always straightforward due to the fact that they are developed primarily for claim purpose. Recent advancements in medical informatics have led to the establishment of standard clinical information systems for the purpose of standardizing disparate EMR data sources into a common data format. The Observational Health Data Sciences and Informatics (OHDSI), a new international organization founded in 2014, established the standardizing system known as the Observational Medical Outcome Partnership (OMOP) common data model (CDM).[20,21] Using the OMOP CDM system, EMR data such as patient demographics, diagnosis, chief complaints, family histories, past medical histories, drug exposures, laboratory results, vital signs, and surgeries could be converted into a standard format.[22]

As the OMOP CDM system is capable of standardizing and integrating disparate EMR data sources, it allows more efficient analysis of large-scale data in a variety of clinical investigations.[20,21] Numerous observational studies have previously been published proving the validity of CDM.[23] To the best of our knowledge, CDM has never been utilized in clinical studies investigating PJI. Therefore, in the present study, we aimed to determine the incidence and risk factors for PJI following primary TJA utilizing CDM.

PATIENTS AND METHODS

Data sources

This retrospective, observational study was conducted at Seoul National University Bundang Hospital, Department of Orthopaedic Surgery between January 2003 and December 2017. We used the OHDSI open-source software and the OMOP CDM version 5.2 database, into which the EMR data were transformed. The database contained de-identified EMR data that were converted to a standard format using the OMOP CDM system. Nearly a 15-year span beginning in 2003, over two million patients' EMR data were transformed and collected in our hospital's CDM database.

Patient selection

We included patients who underwent primary total hip arthroplasty (THA) or total knee arthroplasty (TKA) who were admitted to our urban tertiary referral hospital. The CDM database was searched for cases of primary THA or TKA and their associated diagnoses (avascular necrosis, fracture, osteoarthritis, inflammatory arthritis, rheumatoid arthritis, congenital dysplasia, dislocation, ankylosis, traumatic osteoarthritis, traumatic avascular necrosis, instability, and gout) using the concept identification (ID) defined by the Systemized Nomenclature of Medicine Clinical Terms (SNOMED-CT) (Appendix A). The SNOMED-CT is a computer-processable collection of medical terms pertaining to clinical findings, symptoms, diagnoses, and procedures. It is widely recognized as one of the most comprehensive collections of medical terminology available.[24] Then, using the concept IDs for revision TJA, we identified revision cases among the primary TJA cases in the CDM database (Appendix A). The causes for revision were identified by verifying the concept IDs for the diagnosis (loosening, PJI, periprosthetic fracture, prosthesis failure, dislocation, osteolysis). Among the revision TJA cases, we selected those who underwent revision TJA owing to PJI. Patients who previously underwent primary TJA at an external center were excluded. Additionally, those with a follow-up of fewer than 12 months were excluded.

Risk factors for periprosthetic joint infection

We conducted a review of the prior literature to identify all probable risk factors for PJI.[4-10,12-16,18,25,26] Among these, variables that could not be identified in EMR or converted to CDM, such as intraoperative factors (surgical time, oxygen supply, skin preparation, wound closure, and transfusion), observation length, and prophylaxis against venous thromboembolism, were excluded. We included the following clinical data from the CDM database: demographic variables (age and sex), comorbidities, prior corticosteroid usage history, preoperative laboratory values (complete blood cell counts, albumin, cholesterol, erythrocyte sedimentation rate, and C-reactive protein) and average duration of admission following primary TJA. All clinical data were retrieved in the patients' primary TJA state. Using the SNOMED-CT, we detected comorbidities in the CDM database (Appendix B). The history of prior corticosteroid usage was determined using the RxNorm's concept IDs for corticosteroids (Appendix C). The RxNorm, developed by the National Library of Medicine in the United States of America, establishes standard nomenclatures for

clinical drugs.[27] Laboratory measurements were identified using concept IDs defined by the Logical Observation Identifiers Names and Codes (LOINC), an international standard for identifying medical laboratory observations (Appendix D).

Statistical analysis

Statistical analysis was performed using the R software version version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The chi-square and Fisher exact tests were performed for categorical variables, with the PJI as the dependent variable and the other variables as independent variables. Age was analyzed as a categorical variable by splitting the intervals by 10 years. Two categorical variables (low *vs.* high) were created for blood test results based on our hospital laboratory's reference ranges. The t-tests were used to analyze continuous variables. To identify risk variables for PJI, we used a multivariate logistic regression model and calculated odds ratios (ORs) and 95% confidence intervals (CIs). To avoid selection bias, the results were further validated following propensity score matching for age and sex. The 'MatchIt' package in R was used to perform one-to-five propensity score matching. A p value of <0.05 was considered statistically significant.

RESULTS

There were 12,320 primary TJAs (hip 4,758; knee 7,562) throughout the study period. Avascular necrosis was the most frequently cited cause for THA, whereas osteoarthritis was for TKA. There were 120 revision TJAs (0.97%, 120/12,320), including 71 following THA (1.49%, 71/4,758) and 49 following TKA (0.65%, 49/7,562). For THA, loosening was the most frequent reason for revision, followed by PJI, periprosthetic fracture, prosthesis failure, dislocation, and osteolysis. For TKA, loosening was, likewise, the most frequent reason for revision, followed by PJI, osteolysis, prosthesis failure, and periprosthetic fracture (Table I).

Among 12,320 primary TJAs, 34 revision TJAs (hip, 16; knee, 18) were identified as a result of PJI. Consequently, the incidence of PJI following primary TJA could be estimated to be 0.27% (hip, 0.33%, 16/4,758; knee, 0.23%, 18/7,562). The mean age at the time of primary TJA was 59.8±17.5 (range, 31 to 85) years in hip PJI patients and 71.4±7.2 (range, 56 to 80) years in knee PJI patients. There were 15 males (hip, 9; knee, 6) and

TABLE I
Causes of primary and revision total hip and knee arthroplasty

Primary arthroplasty (n=12,320)						Revision arthroplasty (n=120)					
Hip (n=4,758)			Knee (n=7,562)			Hip (n=71)			Knee (n=49)		
Diagnosis	n	%	Diagnosis	n	%	Diagnosis	n	%	Diagnosis	n	%
AVN	1,648	36.5	OA	7,305	92.8	Loosening	21	27.3	Loosening	28	52.8
Fracture	1,063	23.5	RA	366	4.7	PJI	16	20.8	PJI	18	34
OA	1,040	23	Traumatic OA	76	1	Periprosthetic fracture	16	20.8	Osteolysis	3	5.7
Inflammatory arthritis	186	4.1	AVN	62	0.8	Prosthesis failure	11	14.3	Prosthesis failure	3	5.7
RA	177	3.9	Inflammatory arthritis	35	0.5	Dislocation	10	13	Periprosthetic fracture	1	1.9
Congenital dysplasia	148	3.3	Ankylosis	10	0.1	Osteolysis	3	3.9			
Dislocation	100	2.2	Dislocation	7	0.08						
Ankylosis	80	1.8	Instability	6	0.07						
Traumatic OA	41	1	Fracture	3	0.03						
Traumatic AVN	28	0.6									
Instability	4	0.1									
Gout	1	0.02									

AVN: Avascular necrosis; OA: Osteoarthritis; RA: Rheumatoid arthritis; PJI: Periprosthetic joint infection.

Table II
Demographic variables as risk factors of PJI

Variables	Hip				Knee			
	Revision due to PJI (n=16)	Non-revision (n=4,687)			Revision due to PJI (n=18)	Non-revision (n=7,513)		
	n	n	*p*	Odds ratio (95% CI)	n	n	*p*	Odds ratio (95% CI)
Mean age (year)	62.8±27.4	59.8±17.5			71.4±7.2	66.7±16.1		
Sex			0.188	1.97 (0.70~5.56)			**0.002**	5.67 (2.12~15.18)
Female	7	2,665			12	6,905		
Male	9	2,022			6	608		
Age (year)								
20-29		18						
30-39		160				1		
40-49	2	411	0.384	1.60 (0.35~7.11)		4		
50-59	2	585	>0.99	1.07 (0.24~4.79)		25		
60-69	4	762	0.287	1.87 (0.59~5.89)	1	310	0.532	1.36 (0.18~10.30)
70-79	3	775	>0.99	0.77 (0.17~3.44)	13	2439	**<0.001**	5.40 (1.92~15.18)
80-89	2	1011	0.752	0.55 (0.12~2.48)	3	3945	**0.002**	0.18 (0.05~0.62)
90-99	3	805	0.732	1.20 (0.33~4.28)	1	780	>0.99	0.50 (0.06~3.82)
100-109		156				9		
110-119		4						

PJI: Prosthetic joint infection; CI: Confidence interval; Boldface indicates statistical significance.

TABLE III
Comorbidities and others as risk factors for periprosthetic joint infection following primary total hip arthroplasty

Risk factor	Unadjusted				Adjusted*			
	Revision (n=16)	Non-revision (n=4,687)			Revision (n=16)	Non-revision (n=80)		
	n	n	*p*	Odds ratio (95% CI)	n	n	*p*	Odds Ratio (95% CI)
Comorbidity								
Hypertension	8	749	0.005	4.60 (1.66~12.72)	8	8	<0.001	9.00 (2.65~30.55)
Diabetes mellitus	3	469	0.185	2.24 (0.63~7.99)	3	8	0.386	2.07 (0.49~8.87)
Rheumatoid arthritis	0	289			0	6		
Renal disease	2	184	0.116	3.76 (0.84~16.80)	2	4	0.261	2.71 (0.45~16.26)
Liver disease	2	173	0.105	4.01 (0.89~17.92)	2	4	0.261	2.71 (0.45~16.26)
Heart failure	1	234	0.537	1.35 (0.17~10.38)	1	3	0.524	1.71 (0.17~17.58)
Pulmonary disease	0	138			0	4		
Coagulation disorder	0	6			0	0		
Anemia	1	91	0.256	3.60 (0.46~27.72)	1	0		
Depression	0	186			0	2		
Hypercholesterolemia	2	118	0.054	5.95 (0.98~36.02)	2	2	0.128	5.57 (0.72~42.88)
Previous sepsis	0	5			0	0		
Dementia	0	236			0	3		
Hypothyroidism	0	82			0	0		
Parkinson disease	1	96	0.268	3.41 (0.43~26.23)	1	2	0.425	2.60 (0.22~30.53)
Osteoporosis	1	157	0.401	2.06 (0.26~15.77)	1	1	0.307	5.26 (0.31~88.91)
Peripheral vascular disease	3	349	0.096	3.10 (0.87~11.06)	3	5	0.126	3.46 (0.74~16.27)
Urinary tract infection	2	49	0.011	14.56 (3.20~66.25)	2	0	0.026	NA
Peptic ulcer	1	58	0.172	5.70 (0.73~44.07)	1	1	0.307	5.26 (0.31~88.91)
Cerebrovascular disease	4	562	0.096	5.70 (0.73~44.07)	4	8	0.111	3.00 (0.78~11.53)
Others								
Prior corticosteroid usage	0	290						
Average admission duration after primary TJAs (days)	12.1	12.1	0.98	0.01 (-2.80~2.90)	13.2	11.8	0.53	0.60 (-3.20~5.90)

* Adjusted using the propensity score matching for age and sex; CI: Confidence interval; TJA: Total joint arthroplasty; NA: Not available; Boldface indicates statistical significance.

TABLE IV
Comorbidities and others as risk factors for periprosthetic joint infection following primary total knee arthroplasty

Risk factor	Unadjusted				Adjusted*			
	Revision (n=18)	Non-revision (n=7,513)			Revision (n=18)	Non-revision (n=90)		
	n	n	*p*	Odds ratio (95% CI)	n	n	*p*	Odds Ratio (95% CI)
Comorbidity								
Hypertension	9	3,069	0.43	1.44 (0.57~3.65)	9	30	0.179	2.00 (0.72~5.56)
Diabetes mellitus	4	1,649	>0.99	1.01 (0.33~3.09)	4	15	0.518	1.42 (0.41~4.94)
Rheumatoid arthritis	3	704	0.235	1.93 (0.55~6.69)	3	7	0.365	2.37 (0.55~10.21)
Renal disease	2	275	0.14	3.29 (0.75~14.37)	2	4	0.261	2.68 (0.45~15.92)
Liver disease	0	216			0	1		
Heart failure	0	447			0	7		
Pulmonary disease	2	172	0.063	5.33 (0.97~28.47)	2	1	0.071	11.12 (0.95~130.05)
Coagulation disorder	0	4			0	0		
Anemia	2	76	**0.014**	12.23 (2.76~54.12)	2	0	**0.026**	NA
Depression	2	250	0.12	3.63 (0.83~15.87)	2	2	0.129	5.50 (0.72~41.92)
Hypercholesterolemia	1	341	0.567	1.23 (0.16~9.32)	1	4	> 0.99	1.26 (0.13~12.02)
Previous sepsis	0	0			0	0		
Dementia	0	155			0	1		
Hypothyroidism	1	273	0.487	1.56 (0.20~11.76)	1	3	0.523	1.7 (0.17~17.39)
Parkinson disease	1	105	0.225	4.15 (0.54~31.47)	1	0		
Osteoporosis	2	294	0.156	3.06 (0.70~13.41)	2	2	0.129	5.50 (0.72~41.92)
Peripheral vascular disease	3	1,149	0.748	1.10 (0.32~3.83)	3	8	0.388	2.05 (0.49~8.62)
Urinary tract infection	2	68	**0.011**	13.68 (3.08~60.67)	2	0	**0.026**	NA
Peptic ulcer	0	99			0	0		
Cerebrovascular disease	5	1,506	0.383	1.53 (0.54~4.30)	5	11	0.138	2.76 (0.82~9.25)
Others								
Prior corticosteroid usage	3	330	**0.042**	4.35 (1.25~15.11)	3	0	0.004	NA
Average admission duration after primary TJAs (days)	12.3	11.9	0.74	0.30 (-1.90~2.60)	12.3	11.7	0.68	0.40 (-2.20~3.40)

* Adjusted using the propensity score matching for age and sex; CI: Confidence interval; TJA: Total joint arthroplasty; NA: Not available; Boldface indicates statistical significance.

19 females (hip, 7; knee, 12). The male sex (OR: 5.67) and age range between 70 and 79 years (OR: 5.40) were significantly associated with PJI following primary TKA, whereas no demographic predisposition for PJI following THA was observed (Table II).

Among the comorbid variables identified in the CDM database, HTN (OR: 4.60) and UTI (OR: 14.56) were associated with PJI following primary THA. After adjustment for age and sex, we validated that both HTN and UTI were significant risk factors (Table III). For primary TKA, UTI (OR: 13.68), anemia (OR: 12.23), and prior corticosteroid usage (OR: 4.35) were associated with PJI. After adjustment for age and sex, we validated that UTI, anemia, and prior corticosteroid usage were all significant risk factors (Table IV). However, no evidence of a significant association between PJI and preoperative laboratory values was found (Table V).

DISCUSSION

In the present study, we attempted to determine the incidence of PJI following primary TJA and to investigate risk factors utilizing CDM. We established a relatively large cohort of 12,320 patients with primary TJA using the CDM database, which was adequate to determine any uncommon consequence as PJI. The incidence of PJI was determined to be 0.33% in THA, 0.23% in TKA, and 0.27% in total. In addition, HTN and UTI were found to be associated with PJI following primary hip TJA, and that age between 70 and 79, male sex, UTI, anemia, and prior corticosteroid usage were found to be associated with PJI following primary knee TJA. To the best of our knowledge, this is the first study to apply the CDM to the research on PJI.[28] Moreover, many earlier studies that employed CDM in various research fields focused on pharmacoepidemiologic research

TABLE V
Preoperative laboratory values as risk factors for PJI

Variable	Primary THA				Primary TKA			
	Revision (n=16)	Non-revision (n=4,687)			Revision (n=18)	Non-revision (n=7,513)		
	n	n	*p*	Odds ratio (95% CI)	n	n	*p*	Odds Ratio (95% CI)
Albumin (g/dL)								
Low (<3.3)	2	311	0.282	2.1 (0.5~9.3)	2	385	0.236	2.3 (0.5~10.1)
High (>5.2)		11						
Cholesterol (mg/dL)								
Low (<200)	8	2836	0.399	0.6 (0.2~1.8)	12	5005	0.992	0.9 (0.4~2.7)
High (>240)	1	327	>0.99	0.9 (0.1~6.9)	1	609	>0.99	0.7 (0.1~5)
WBC (10^9/L)								
Low (<4)	0	191			2	342	0.198	2.6 (0.6~11.4)
High (>11)	1	195	0.487	1.6 (0.2~12.1)	0	202		
Eosinophils (%)								
Low (<1)	3	1214	0.772	0.7 (0.2~2.3)	3	851	0.461	1.5 (0.4~5.2)
High (>5)	2	434	0.653	1.4 (0.3~6.3)	2	878	>0.99	0.9 (0.2~3.9)
Hematocrit (%)								
Low (<36)	3	1117	>0.99	0.8 (0.2~2.7)	8	2647	0.419	1.5 (0.6~3.7)
High (>48)		146			1	36	0.085	12.2 (0.9~158.2)
Lymphocytes (%)								
Low (<20)	6	1531	0.585	1.4 (0.5~3.9)	3	747	0.415	1.8 (0.5~6.3)
High (>44)		294			1	845	0.712	0.5 (0.1~3.5)
Monocytes (%)								
Low (<2)	1	45	0.137	7.4 (0.9~57.2)		26		
High (>9)	2	811	>0.99	0.7 (0.2~3.3)	5	1277	0.213	1.9 (0.7~5.3)
Neutrophils (%)								
Low (<50)		723			1	1906	0.057	0.2 (0.02~1.3)
High (>75)	2	1076	0.543	0.5 (0.1~2.3)	1	302	0.522	1.4 (0.2~10.6)
ESR (mm/h)								
Normal (0-9)	1	1221	0.078	0.2 (0.02~1.3)	3	1871	0.587	0.6 (0.2~2.1)
High (>9)	13	2791	0.078	5.7 (0.7~43.5)	15	5620	0.587	1.7 (0.5~5.8)
CRP (mg/dL)								
Normal (0-0.5)	7	2748	0.251	0.5 (0.2~1.4)	9	5146	0.084	0.5 (0.2~1.1)
High (>0.5)	7	1330	0.251	2.1 (0.7~5.9)	9	2325	0.084	2.2 (0.9~5.6)

PJI: Prosthetic joint infection; THA: Total hip arthroplasty; TKA: Total knee arthroplasty; CI: Confidence interval; WBC: White blood cell; ESR: Erythrocyte sedimentation rate; CRP: C-reactive protein.

involving disease treatment and epidemiological analysis of disease-related mortality.[23,29] In this study, we concentrated on potential risk variables for PJI, including comorbidities, prior corticosteroid usage, and laboratory values, and were able to identify risk factors.

According to several previous reports based on national registry or claim database, the incidence of PJI was approximately 2.0 to 2.4% in the United states, 1.6% in Canada, and 2.3-2.8% in Korea.[30-32] However, the incidences from single institution research have been observed to be much lower than those from national data in general, ranging between around 0.4 and 0.9%.[6,15] This mismatch was previously ascribed to the fact that single institution research often utilized more precise definitions of PJI.[33] This study indicated 0.27% incidence of PJI, which was lower than previously report rates. As discussed in further detail in the following section on study limitations, it is possible that not all PJI cases were included

in this study due to methodological shortcomings, resulting in a lower incidence. Additional multi-center investigations with a larger cohort are required to ascertain whether institutional or regional variations in PJI incidence exist.

Age and the risk of PJI after TKA were shown to be associated in this study, which is consistent with previous studies.[12,16,25] While it seems that older patient age is associated with poor nutritional state and, hence, a higher risk of infection, some studies have shown an increased risk of revision in comparatively younger patients.[13,14,18] Additionally, we found male sex as a substantial risk factor for PJI following TKA, confirming earlier findings.[3,7,8,15,18] A study found that men were more susceptible to surgical trauma and tissue necrosis than women were.[3] Additionally, since males are engaged with more active lifestyles, high exercise volume following after TJA may develop in overuse, necessitating revision surgery.

Previously, it has been shown that high blood pressure is associated with delayed healing of surgical wounds after TJA, and this study confirms this association in THA.[10,26] This study also found that UTI was associated with an increased incidence of PJI following both hip and knee TJA. In general, women are more likely to get UTI than males, with a reported prevalence of 5.1 to 36% in women undergoing primary TJA.[2,7] As a consequence, we believe that patients who present with symptomatic UTI should be treated prior to TJA.[6] Additionally, underlying anemia was shown to be a risk factor for PJI after TKA. Nutritional deprivation is a common cause of anemia. Several studies have shown that patients with primary TJA who are anemic prior to surgery are more likely to require blood transfusions, which increase the risk of postoperative infection.[6,9,34] As a result, we suggest that patients should be assessed for anemia prior to TJA and treated appropriately with iron supplements or recombinant human erythropoietin to minimize the occurrence of PJI.[6,35]

Following TKA, patients who previously used corticosteroids were shown to be at an increased risk of developing PJI, consistent with previous reports.[7,11] The relationship between corticosteroid usage and PJI is certainly believed to be influenced by the anti-inflammatory and immunosuppressive actions of corticosteroids.[4] Additionally, corticosteroid use may have an adverse effect on bone metabolism, which may lead to significant loss of bone mineral.[36]

The primary advantage of CDM-based research is that it can be conducted on a larger scale, at a lower cost, and in a shorter amount of time than conventional studies.[20] Numerous observational studies proving the validity and reliability of CDM have been published lately.[23] Additionally, it protects the safety and confidentiality of patients by employing CDM tool results rather than particular patient information.[37] In our study, the individual patient identifiers were eliminated during the transformation to the CDM to ensure patients' safety and confidentiality. Additionally, the CDM is crucial for collaborative research involving various organizations.[20,21,37] Due to the fact that each hospital's patient information structure is unique, it is vital to standardize patient information when collaborating with numerous hospitals using the CDM tool. However, the remaining discrepancies in data formats and coding methods continue to be substantial hurdles to the CDM tool's data standardization.[38]

Nonetheless, this study has some limitations that should be acknowledged. First, we identified cases of PJI on the assumption that all patients with PJI following primary TJA underwent revision TJA. However, as some PJI patients treated with debridement, antibiotics, and implant retention rather than revision TJA were not included, it is possible that the number of PJI patients was underestimated in this study. In addition, our study included only patients who underwent both primary and revision TJA at a single institution. Since individuals who received revision TJA at another institution after primary TJA in our institution were excluded, this could be another probable reason for the underestimation. Second, although we sought to incorporate all previously documented risk variables for PJI, we excluded some that were not identified in the EMR or were not converted to CDM, such as body mass index (BMI), operation time, and venous thromboembolism prophylaxis. Given that multiple prior studies, including a recent meta-analysis, have revealed an association between BMI and PJI, it is possible that different findings might have been observed, if BMI had been included in this study's risk factor analysis.[6,9,17] Further data transformation technologies are required to analyze additional clinical variables, such as comprehensive demographic information, intraoperative variables, and imaging findings. Third, only patients who underwent primary hip or knee TJA were included in this study. research. While TJAs for other joints such as the shoulder, ankle, elbow, and wrist are less common, incorporating them in the study might result in different results. To ensure that our findings apply to all TJAs, we believe it is necessary to include outcomes for relatively

infrequent TJAs. Finally, this study enrolled subjects from a single institution. Although we established a large cohort of 12,320 patients with primary TJA, we analyzed data from just one institution, which may be inadequate to generalize our findings.

In conclusion, the incidence of PJI following primary TJA was found to be 0.27%. In addition, HTN and UTI were found to be risk factors for PJI following primary THA, while the age between 70 and 79, male sex, UTI, anemia, and prior corticosteroid usage were identified as risk factors for PJI following primary TKA. Based on these findings, prior to surgery, it is crucial to determine whether the patient has certain risk factors for PJI and, if feasible, to address correctable risk factors in advance. This study indicates the viability of employing CDM to examine the risk factors of PJI and provided the basis for future CDM-based risk factor analysis. Additional research utilizing CDM data from multiple institutions for large-scale analysis is necessary to elucidate true risk factor associations and to identify institutional or regional disparities in PJI occurrence.

Ethics Committee Approval: The study protocol was approved by the Institutional Review Board of the Seoul National University Bundang Hospital (Date/No.: January 16, 2019/B-1902/520-101). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept and design: Y.J.C., H.S.G.;Acquisition, analysis, or interpretation of data: K.J.B., S.J.J.; Drafting of the manuscript: K.J.B., Y.J.C, H.S.G.; Critical revision of the manuscript for important intellectual content; All authors agreement to the published version of the manuscript.

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APPENDIX A
Procedure and concept identification

Procedure	Concept ID	Domain	Vocabulary
Primary total knee arthroplasty	4311039	Procedure	SNOMED-CT
Primary total hip arthroplasty	4203771	Procedure	SNOMED-CT
Revision total knee arthroplasty	4058591, 4106397	Procedure	SNOMED-CT
Revision total hip arthroplasty	4090926, 4010119, 4266062	Procedure	SNOMED-CT

ID: Identification; SNOMED-CT: Systemized nomenclature of medicine clinical terms.

APPENDIX B

Diagnosis for comorbidity and concept identification

Concept name	Concept ID	Domain	Vocabulary
Hypertension	312648, 317895, 317898, 318437, 319826, 320128, 37311147, 37311148, 4028741, 4167358, 4209293, 42538697, 4262182		
Diabetes mellitus	30968, 192279, 192691, 195771, 200687, 201254, 201820, 201826, 318712, 321052, 321822, 373999, 376065, 376112, 376114, 376683, 377552, 377821, 378743, 380096, 434480, 435216, 438476, 442793, 443727, 443729, 443730, 443731, 443732, 443733, 443735	Condition	SNOMED-CT
Rheumatoid arthritis	80809, 4035611, 4083556, 4114439, 4116150, 4116151, 4116440, 4117687, 4132809, 4253901	Condition	SNOMED-CT
Renal disease	75865, 192276, 192359, 192440, 192686, 192958, 192964, 193016, 193519, 193782, 194686, 194994, 194995, 195072, 195597, 195861, 196813, 197320, 197656, 198124, 198185, 200687, 200766, 200781, 201111, 201313, 201675, 436232, 437992, 440529, 443597	Condition	SNOMED-CT
Liver disease	192675, 192680, 193142, 193256, 193344, 194280, 194417, 194560, 194861, 194984, 194990, 195392, 195749, 196463, 197490, 197654, 197676, 197795, 199767, 200656, 201343, 201612, 201901, 312723, 434300, 436342, 444117, 444421, 4026125, 4026131	Condition	SNOMED-CT
Heart failure	134057, 137212, 138255, 141124, 195556, 198571, 312327, 312723, 313500, 314378, 314658, 315069, 315286, 315831, 316139, 316428, 316822, 317000, 317576, 317814, 318443, 318773, 319034, 319825, 319835, 319843, 319844, 320425, 320746, 321119, 323119	Condition	SNOMED-CT
Pulmonary disease	252348, 252942, 253121, 253954, 254320, 255454, 255477, 255573, 256018, 256023, 256622, 256722, 257004, 257010, 257094, 257583, 257825, 257907, 258684, 260026, 260034, 260041, 260630, 261327, 261393, 261600, 261880, 320136, 432541, 433134, 433233	Condition	SNOMED-CT
Coagulation disorder	432296, 432585, 432863, 432869, 436093, 4028488, 4055720, 4060621, 4078700, 4098292, 4098765, 7098766, 4101592, 4010593, 4010594, 4010596, 4179872, 4179872, 4197062, 4230381, 4230381, 4231770, 4295287, 4314802	Condition	SNOMED-CT
Anemia	22281, 26942, 28396, 30683, 30978, 136949, 137829, 140681, 432282, 432295, 432588, 432868, 432875, 432881, 433168, 434156, 434621, 434622, 434894, 435503, 435789, 436083, 436659, 437247, 437834, 439777, 440218, 440977, 440979, 441269, 443961	Condition	SNOMED-CT
Depression	374009, 433440, 436665, 437528, 438727, 439243, 439254, 440383, 443432, 4149320, 4151170, 4195572, 4282096, 4282316, 4308866, 4332994, 4338031	Condition	SNOMED-CT
Hypercholesterolemia	4029259, 4029305, 4134862, 4220010	Condition	SNOMED-CT
Previous sepsis	132797, 133956, 4029281, 4204036, 36715430, 40486058, 40486059, 40488629, 40486631, 40486685, 40487059, 40487062, 40487063, 40487064, 40487616, 40489907, 40489908, 40489909, 40489910, 40489912, 40491961, 40493038, 40493039, 40493415	Condition	SNOMED-CT
Dementia	374326, 374888, 375791, 376085, 376094, 376095, 376946, 377254, 377527, 378125, 378419, 378726, 379778, 379784, 380701, 380986, 381832, 439276, 443605, 765653, 762704, 762497, 4046090, 4046089, 4048875, 4092747, 4097384, 4182210, 4182539, 4196433, 4204688, 4218017, 4220313, 427746, 4278830, 4314734	Condition	SNOMED-CT
Hypothyroidism	140673, 4034815, 40609121, 4183422, 4220368, 4223217, 45757058	Condition	SNOMED-CT
Parkinson disease	374013, 381270, 36716783, 37110499, 37395785, 37396747, 4140090, 4140881, 4231949, 45765396	Condition	SNOMED-CT
Osteoporosis	80502, 80824, 81390, 4002134, 4003481, 4004622, 4010333, 4136988, 417335, 4305731, 4344377, 4347298, 45766159	Condition	SNOMED-CT
Peripheral vascular disease	321052, 760977, 764026, 765881, 3654996, 4124836, 4131908, 432544, 36713094, 44782426, 44782775	Condition	SNOMED-CT
Urinary tract infection	81902, 4056621, 4056622, 4114033, 4116490, 4116491, 4177850, 4208664, 42203228, 4311853, 4329106, 4330644, 4331815, 35610224, 37016368, 37016369, 37016370, 37311936, 45763849, 45770841	Condition	SNOMED-CT
Peptic ulcer	22665, 23237, 23247, 23808, 24076, 24397, 24973, 26718, 27026, 30439, 30442, 30770, 31335, 194986, 195584, 198187, 200771, 201069, 4003018, 4006994, 4012219, 4024846, 4024849, 4027663, 4028242, 4046500, 4054392, 4057053, 4057060, 4095410, 4134146, 4146517, 4163865, 4169394, 4172869, 4174044, 4174823, 4194543, 4204555, 4206466, 4235740, 4247008, 4265600, 4274696, 4273101, 4291028, 4318534, 4319441, 4338225, 36713503, 37203956	Condition	SNOMED-CT
CVD	381316, 761785, 761789, 761791, 761792, 761793, 761794, 761795, 761796, 761797, 761798, 761835, 761836, 762339, 762340, 762344, 762345, 764813, 764814, 764815, 764816, 765568, 4045734, 4046358, 4046359, 4046360, 4046363, 4110196, 4112022, 4110196, 4112022, 4142739, 4153352, 4159140, 4310996, 35609033, 36684840, 42535113, 42535114, 42535508, 42535511, 42535512, 42539166, 43530669, 43530670, 43531605	Condition	SNOMED-CT

ID: Identification; SNOMED-CT: Systemized nomenclature of medicine clinical terms; CVD: Cerebrovascular disease.

APPENDIX C Concept identification for corticosteroid use			
Drug	Concept ID	Domain	Vocabulary
Steroid	903963, 920458, 975125, 1506270, 1518254, 1550557	Drug	RxNorm

ID: Identification.

APPENDIX D Laboratory measurements and concept identification			
Concept name	Concept ID	Domain	Vocabulary
Albumin (g/dL)	3024561	Measurement	LOINC
Cholesterol (mg/dL)	3027114	Measurement	LOINC
WBC (10^9/L)	3000905	Measurement	LOINC
Eosinophils (%)	3010457	Measurement	LOINC
Hematocrit (%)	3023314	Measurement	LOINC
Lymphocytes (%)	3037511	Measurement	LOINC
Monocytes (%)	3011948	Measurement	LOINC
Neutrophils (%)	3012608	Measurement	LOINC
ESR (mm/h)	3015183	Measurement	LOINC
CRP (mg/dL)	3028766	Measurement	LOINC

ID: Identification; LOINC: Logical observation identifiers names and codes; WBC: White blood cell; ESR: Erythrocyte sedimentation rate; CRP: C-reactive protein.