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Trends in Revision Knee Arthroplasty for Prosthetic Joint Infection: A Single-Center Study of 384 Knees at a High-Volume Center Between 2008 and 2021

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ABSTRACT

Background: Prosthetic joint infection (PJI) is one of the most devastating complications after total knee arthroplasty (TKA), and comorbidities increase the risk. We examined whether a temporal change has occurred in the demographics, especially regarding comorbidities, of patients who have PJI and were treated at our institution over a 13-year study period. In addition, we assessed the surgical methods used and the microbiology of the PJIs.

Methods: Revisions (n = 384, 377 patients) due to PJI of the knee performed at our institution between 2008 and September 2021 were identified. All included PJIs fulfilled the 2013 International Consensus Meeting diagnostic criteria. The surgeries were categorized into one of the following categories: debridement, antibiotics, and retention (DAIR), 1-stage revision, and 2-stage revision. Infections were classified as early, acute hematogenous, and chronic.

Results: No changes in the median age of the patients nor comorbidity burden were observed during the study period. However, the proportion of 2-stage revisions decreased remarkably from 57.6% in 2008 to 2009 to 6.3% in 2020 to 2021. A DAIR was the most used treatment strategy, but the proportion of 1-stage revisions increased the most. In 2008 to 2009, 12.1% of the revisions were 1-stage, but in 2020 to 2021, the proportion was 43.8%. The most common pathogen was *Staphylococcus aureus* (27.8%).

Conclusion: The comorbidity burden remained at the same level with no trends. A DAIR was the most used strategy, but the proportion of 1-stage revisions rose to almost the same level. The incidence of PJI varied between the years, but remained relatively low.

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Prosthetic joint infection (PJI) is one of the most devastating complications after total knee arthroplasty (TKA). Moreover, PJI is not only a tremendous burden for individual patients, but also for global health care systems because it is associated with recurrent surgeries, increased mortality risks, and inferior patient-reported outcomes [1–3].

The risk for developing PJI after TKA has been reported to be under 2% within 2-year follow-up [4,5]. In a longer follow-up period, the cumulative incidence has been reported to range between 0.06% and 0.08% per prosthesis-year [6]. During the last decades, decreasing incidences of PJI of the knee have been reported [7,8]. However, increases in the incidences of PJIs have also been reported [9], and these increases are expected to continue [10]. In addition, the comorbidity burden of patients undergoing primary TKA has also increased and is expected to increase further [11]. An increase in the prevalence of diabetes and obesity among TKA patients [11] may lead to an even greater increase in the incidence of PJI, as they are both known risk factors [12].

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Traditionally, the surgical treatment of PJI has been based on treatment algorithms, where early infections are preferably treated with debridement, antibiotics, and retention (DAIR) and late infections with 2-stage revision surgery [13,14]. However, spacer retention after the first stage of an intended 2-stage revision has become a viable treatment option (a so-called "1.5-stage exchange arthroplasty"), as both clinical outcomes and reinfection rates have also been reported to be acceptable with chronic infections [15,16]. Furthermore, 1-stage revisions have also become more popular in recent years [9].

The microbiology of PJI of the knee has been reported to be associated with the time after prosthesis implantation and the route of acquisition. Thus, early and acute hematogenous infections are mainly caused by *Staphylococcus aureus* and delayed infections by coagulase-negative staphylococci (CNS) [17,18]. However, high rates of CNSs have also been observed in early infections [19].

To our best knowledge, no previous study has examined how the demographics of patients who have PJI of the knee, the surgical treatment strategies for PJI, and the distribution of pathogens have changed during the past decade. Therefore, in the present study, we aimed to assess (1) whether there has been a change in the demographics of patients who have a PJI; (2) whether there has been a change in the surgical treatment of PJI; and (3) whether there has been a change in microbiological findings.

Materials and Methods

Our institution is a high-volume academic referral center focused on joint arthroplasty surgery, with an annual volume of more than 3,000 primary and over 200 revision TKAs. In this retrospective cohort study, we identified all revision surgeries performed for PJI of the knee at our institution between January 1st, 2008, and September 12th, 2021, by searching the ICD-10 (International Classification of Diseases 10th revision) code T84.5 (Infection and inflammatory reaction due to internal joint prosthesis). After excluding superficial wound infections and 2-stage operations where information on the first surgery was not available, the PJI diagnosis was confirmed with 2013 International Consensus Meeting diagnostic criteria [20]. If the criteria were not fulfilled, the case was excluded. Only the first revisions due to PJI were included, and those patients who underwent revision due to PJI in both knees were analyzed as 2 separate operations.

The patient data were obtained using our institution's electronic data lake as well as electronic health records (EHR). Our institution's electronic data lake is a prospectively filled database, where specific details of every treatment period (eg, details of surgery, prosthesis, laboratory results, medication, comorbidities) are collected and documented. The EHRs contain information related to patient care, whereas the data lake contains more comprehensive information on the surgical details. The following patient demographics were collected from the data lake and the EHRs: age, sex, body mass index (BMI), American Society of Anesthesiology (ASA) classification, and comorbidities. Charlson comorbidity index (CCI) scores were calculated separately for each patient [21]. In addition, we also recorded the date of the primary surgery, the date of the last noninfectious operation to the ipsilateral joint, and the date from the beginning of the symptoms before revision surgery. Information on the presence of a fistula and intraoperative microbiological findings from tissue specimens were also collected from the EHRs. All the microbiology analyses were performed in the accredited microbiology laboratory of the local university hospital. In accordance with Finnish legislation, no institutional review board hearing was required because of the retrospective register-based study design and because the patients were not contacted.

The surgeries were categorized into 1 of the following 3 categories: DAIR; 1-stage revision; or 2-stage revision. The DAIR included all surgeries where the joint capsule was opened and the tibial liner possibly replaced, but neither the tibial nor the femoral component were replaced or removed. In 1-stage revision, all the components were replaced in 1 operation, whereas in 2-stage revision, the components were sequentially removed and replaced in 2 operations with a period of spacer prosthesis or static spacer in between. If the planned second stage was not performed due to a satisfactory outcome from the first-stage operation, the surgery was categorized as 1-stage revision, as suggested by the Musculoskeletal Infection Society [22].

To reflect the pathogenesis of the PJI and to produce results that are applicable in a clinical setting, the infections were classified as early ($\leq$90 days from the previous surgery), acute hematogenous (>90 days from the previous surgery AND <28 days of symptoms), and chronic (>90 days from the previous surgery AND $\geq$28 days of symptoms) [14,18,23].

Patient and Surgical Demographics

A total of 384 PJI revisions (377 patients) were performed at our institution. Of these, 148 (38.5%) were early infections, 147 (38.3%) acute hematogenous infections, and 89 (32.2%) chronic infections (Fig. 1). In total, 152 (39.6%) DAIRs, 104 (27.1%) 1-stage revisions, and 128 (33.3%) 2-stage revisions were performed. Of the 1-stage revisions, 21 (20.2%) were originally planned to be 2-stage revisions, but the second stage was not performed due to the satisfactory outcome from the first stage. Most of the DAIRs (n = 78, 51.3%) and 1-stage revisions (n = 38, 36.5%) were performed for acute hematogenous infections, whereas most of the 2-stage revisions (n = 57, 44.5%) were performed for chronic infections. The median age of the patients was 72 years (range, 37 to 94) and 50.5% (n = 194) were women (See Tables 1 and 2).

Data Analyses

Means with standard deviations (SD) were presented for normally distributed variables and medians with interquartile ranges (IQR) for variables with non-Gaussian populations. Categorical variables were presented as counts and percentages. To examine the changes during our study period, patient demographics and the microbiology of the PJIs were compared in a longitudinal setting using descriptive statistics. Moreover, to avoid selection bias, patient demographics and the microbiology of the PJIs were compared in 2-year admission groups, rather than in yearly groups.

As our institution is a tertiary referral center, not all revisions were performed on patients who had undergone their primary TKA at our institution. Therefore, incidences were calculated based on the number of primary TKAs performed at our institution, and the number of PJIs of which the primary arthroplasty was performed at our institution. Referral PJIs and those PJIs that occurred after revision TKA were not included in the incidence calculations. All analyses were performed using R (version 4.1.2; R Foundation for Statistical Computing, Vienna, Austria). The results of this study are reported according to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines [24].

Results

Trends in Demographics and Surgical Treatment

Neither the median age of the patients nor the comorbidity burden changed during the study period. The proportion of ASA-class 4 patients was between 4.8% and 14.3% with no trends, and

Table 1
PJI Patient Characteristics and Preoperative Risk Factors Stratified by Type of Infection.

Variable	Early (n = 148)	Acute Hematogenous (n = 147)	Chronic (n = 89)
Patient characteristics			
Women, n (%)	65 (43.9)	72 (49)	57 (64)
Age, in years, median (IQR)	70 (62–77)	74 (65–81)	73 (62–78)
BMI, mean (range)	30.9 (42 to 89)	30.3 (48 to 94)	30.8 (37 to 93)
BMI ≥30, n (%)	84/145 (57.9)	64/127 (50.4)	44/84 (52.4)
BMI ≥35, n (%)	40/145 (27.6)	35/127 (27.6)	17/84 (20.2)
CCI, median (range)	3 (0–6)	3 (0–7)	3 (0–8)
CCI ≥3, n (%)	92/148 (62.2)	99/147 (67.3)	64/89 (71.9)
ASA-class, n (%)			
1	3 (2)	3 (2)	2 (2.2)
2	33 (22.3)	23 (15.6)	17 (19.1)
3	100 (67.6)	90 (61.2)	62 (69.7)
4	8 (5.4)	26 (17.7)	6 (6.7)
5	0	2 (1.4)	0
NA	4 (2.7)	3 (2)	2 (2.2)
Co-morbidities, n (%)			
Diabetes mellitus	32/143 (22.4)	33/119 (27.7)	14/83 (16.9)
Rheumatoid arthritis	12/137 (8.8)	12/119 (10.1)	14/80 (17.5)
Chronic kidney disease	1/141 (0.7)	6/118 (5.1)	2/82 (2.4)
Operation type, n (%)			
DAIR	73 (49.3)	78 (53.1)	1 (1.1)
One-stage revision	35 (23.6)	38 (25.9)	31 (34.8)
Two-stage revision	40 (27)	31 (21.1)	57 (64)
Static spacer	2 (5)	1 (3.2)	6 (10.5)
Surgical characteristic			
Time since previous operation, median (IQR), d	22 (16–29)	1,242 (357–3,240)	686 (284–1,555)
Symptom duration, median (IQR), d	12 (4–20)	5 (3–9)	100 (64–264)
Sinus tract, n (%)	107/146 (73.3)	5/147 (3.4)	10/86 (11.6)

Infections are classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms) and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms).
DAIR, debridement, antibiotics, and implant retention; d, days; y, years; IQR, interquartile range; CCI, charlson comorbidity index; ASA, American Society of Anesthesiology; BMI, body mass index.

Table 2
PJI Patient Characteristics and Preoperative Risk Factors, Stratified by the Operation type.

Variable	DAIR (n = 152)	One-Stage (n = 104)	Two-Stage (n = 128)
Patient characteristics			
Women, n (%)	70 (46.1)	51 (49)	73 (57)
Age, in years, median (IQR)	70 (63–77)	74 (66–81)	70 (62–78)
BMI, mean (range)	31.1 (42 to 94)	29.2 (37 to 94)	31.3 (45 to 93)
BMI ≥30, n (%)	80/144 (55.6)	39/91 (42.9)	73/121 (60.3)
BMI ≥35, n (%)	45/144 (31.3)	17/91 (18.7)	30/121 (24.8)
CCI, median (range)	3 (0–7)	3 (0–8)	3 (0–6)
CCI ≥3, n (%)	94 (61.8)	79 (76)	82 (64.1)
ASA-class, n (%)			
1	3 (2)	3 (2.9)	2 (1.6)
2	33 (21.7)	13 (12.5)	27 (21.1)
3	101 (66.4)	68 (65.4)	83 (64.8)
4	11 (7.2)	17 (16.3)	12 (9.4)
5	1 (0.7)	1 (1)	0
NA	3 (2)	2 (1.9)	4 (3.1)
Co-morbidities, n (%)			
Diabetes mellitus	34/132 (25.8)	16/96 (16.7)	29/117 (24.8)
Rheumatoid arthritis	12/132 (9.1)	11/95 (11.6)	18/112 (16.1)
Chronic kidney disease	4/132 (3)	3/95 (3.2)	2/114 (1.8)
Infection type, n (%)			
Early	73 (48)	35 (33.7)	40 (31.3)
Acute hematogenous	78 (51.3)	38 (36.5)	31 (24.2)
Chronic	1 (0.7)	31 (29.8)	57 (44.5)
Surgical characteristic			
Time since previous operation, median (IQR), d	127 (19–1,272)	312 (34–1,304)	296 (42–1,420)
Symptom duration, median (IQR), d	5 (3–13)	13 (5–29)	21 (6–78)
Sinus tract, n (%)	51 (33.6)	28 (26.9)	43 (33.6)
Static spacer, n (%)	-	-	9 (20.9)

Infections are Classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms) and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms).
DAIR, debridement, antibiotics, and implant retention; d, days; y, years; IQR, interquartile range; CCI, charlson comorbidity index; ASA, American Society of Anesthesiology; BMI, body mass index.

Table 3
Patient Demographics During Our Study Period, Stratified by the Year of Operation.

Variable	2008-09 (n = 33)	2010–11 (n = 50)	2012–13 (n = 45)	2014–15 (n = 53)	2016–17 (n = 62)	2018–19 (n = 77)	2020–21 (n = 64)
Patient characteristics							
Women, n (%)	16 (48.5)	30 (60)	26 (57.8)	24 (45.3)	37 (59.7)	35 (45.5)	26 (40.6)
Age, median (IQR), y	70 (64–79)	72 (62–78)	69 (60–80)	73 (66–79)	72 (65–81)	72 (63–79)	72 (62–77)
BMI, mean (sd)	29.7 (5.5)	30.5 (6.2)	31.9 (6.7)	30.8 (7.3)	29.4 (5.5)	31.6 (5.3)	30.6 (6.4)
BMI ≥30, n (%)	16/31 (51.6)	26/44 (59.1)	24/41 (58.5)	20/49 (40.8)	27/60 (45)	43/70 (61.4)	36/61 (59)
BMI ≥35, n (%)	7/31 (22.6)	11/44 (25)	9/41 (22)	13/49 (26.5)	10/60 (16.7)	26/70 (37.1)	16/61 (26.2)
CCI, median (range)	3 (1–5)	3 (0–7)	3 (0–6)	3 (1–6)	3 (0–8)	3 (0–7)	3 (0–5)
CCI ≥3, n (%)	24 (72.7)	36 (72)	23 (51.1)	36 (67.9)	42 (67.7)	52 (67.5)	42 (65.6)
ASA-class, n (%)							
1	0	0	2 (4.4)	1 (1.9)	2 (3.2)	1 (1.3)	2 (3.1)
2	6 (18.2)	13 (26)	9 (20)	8 (15.1)	13 (21)	9 (11.7)	15 (23.4)
3	14 (42.4)	30 (60)	31 (68.9)	38 (71.7)	44 (71)	55 (71.4)	40 (62.5)
4	4 (12.1)	7 (14)	3 (6.7)	5 (9.4)	3 (4.8)	11 (14.3)	7 (10.9)
5	1 (3)	0	0	1 (1.9)	0	0	0
NA	8 (24.2)	0	0	0	0	1 (1.3)	0
Co-morbidities, n (%)							
Diabetes mellitus	9/30 (30)	10/48 (20.8)	7/42 (16.7)	15/46 (32.6)	13/53 (24.5)	11/64 (17.2)	14/62 (22.6)
Rheumatoid arthritis	6/30 (20)	7/49 (14.3)	4/40 (10)	5/41 (12.2)	9/53 (17)	3/64 (4.7)	7/62 (11.3)
Chronic kidney disease	0	4/49 (8.2)	0	1/43 (2.3)	1/53 (1.9)	3/64 (4.7)	0
Infection type, n (%)							
Early	17 (51.5)	15 (30)	12 (26.7)	15 (28.3)	23 (37.1)	31 (40.3)	35 (54.7)
Acute hematogenous	11 (33.3)	19 (38)	21 (46.7)	24 (45.3)	24 (38.7)	24 (31.2)	20 (31.3)
Chronic	5 (15.2)	16 (32)	12 (26.7)	14 (26.4)	15 (24.2)	18 (23.4)	9 (14.1)
Operation type, n (%)							
DAIR	10 (30.3)	12 (24)	14 (31.1)	24 (45.3)	31 (50)	29 (37.7)	32 (50)
One-stage revision	4 (12.1)	4 (8)	4 (8.9)	11 (20.8)	17 (27.4)	36 (46.8)	28 (43.8)
Two-stage revision	19 (57.6)	34 (68)	27 (60)	18 (34)	14 (22.6)	12 (15.6)	4 (6.3)
Static spacer	0	3 (8.8)	1 (3.7)	2 (11.1)	1 (7.1)	1 (8.3)	1 (25)

Infections are Classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms), and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms).
DAIR, debridement, antibiotics, and implant retention; d, days; y, years; IQR, interquartile range; sd, standard deviation; CCI, charlson comorbidity index; ASA, American Society of Anesthesiology; BMI, body mass index.

the median Charlson's comorbidity index score was 3 throughout the study period (Table 3).

The incidence of PJI or infection types did not show a clear trend, but the yearly changes in the incidences were large. The smallest incidence, 0.54 per 100 primary TKAs, was in 2008, whereas the largest incidence, 1.60 per 100 primary TKAs, was in 2011. The incidence of early infections was between 0.15 and 0.70 per 100 primary TKAs throughout the study period, but the yearly variation was large within those as well (Table 4, and Fig. 2).

During our study period, the proportion of 2-stage revisions decreased remarkably. In 2008 to 2009, for example, 57.6% (19 of 33) of the operations were 2-stage operations. In 2020 to 2021,

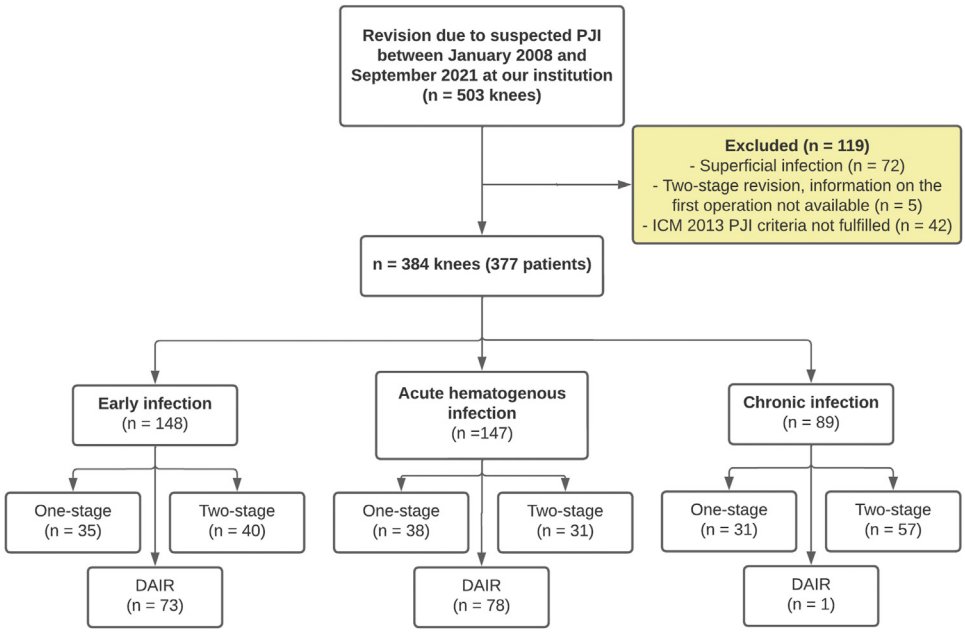

Fig. 1. Flowchart of the patients treated at our institution between January 2008 and September 2021.

Table 4
Yearly Incidence of the PJI Revisions Performed at Our Institution Between 2008 and 2021.

Variable	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Operation type, n														
Primary TKA	1,286	1,223	1,273	1,061	1,188	1,208	1,183	1,320	1,783	1,888	2,143	2,651	2,873	2,245
PJI revision	7	11	18	17	10	9	13	9	24	17	26	27	33	17
Infection type, n														
Early	5	5	5	5	3	2	3	2	9	10	8	15	20	11
Acute hematogenous	1	3	10	5	4	7	5	6	12	3	14	5	9	3
Chronic	1	3	3	7	3	0	5	1	3	4	4	7	4	3
Type of the revision, n														
DAIR	2	4	6	4	3	6	5	6	15	7	13	9	18	10
One-stage revision	1	1	1	1	1	0	4	2	4	6	9	16	13	6
Two-stage revision	4	6	11	12	6	3	4	1	5	4	4	2	2	1
Incidence per 100 primary TKAs														
Overall	0.54	0.90	1.41	1.60	0.84	0.75	1.10	0.68	1.35	0.90	1.21	1.02	1.15	0.76
Early infections	0.39	0.41	0.39	0.47	0.25	0.17	0.25	0.15	0.50	0.53	0.37	0.57	0.70	0.49
Acute hematogenous infections	0.08	0.25	0.79	0.47	0.34	0.58	0.42	0.45	0.67	0.16	0.65	0.19	0.31	0.13
Chronic infections	0.08	0.25	0.24	0.66	0.25	0	0.42	0.08	0.17	0.21	0.19	0.26	0.14	0.13
DAIR	0.16	0.33	0.47	0.38	0.25	0.50	0.42	0.45	0.84	0.37	0.61	0.34	0.63	0.45
One-stage revision	0.08	0.08	0.08	0.09	0.08	0	0.34	0.15	0.22	0.32	0.42	0.60	0.45	0.27
Two-stage revision	0.31	0.49	0.86	1.13	0.51	0.25	0.34	0.08	0.28	0.21	0.19	0.08	0.07	0.04

The Number of PJI Revisions is Calculated Based on the Number of PJIs Whose Primary Knee Arthroplasty was Performed at Our Institution. Infections are Classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms) and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms).
TKA, total knee arthroplasty; DAIR, debridement, antibiotics, and implant retention.

however, the proportion had decreased to 6.3% (4 of 64). The proportion of 1-stage revisions increased the most. In 2008 to 2009, 12.1% (4 of 33) of the revisions were 1-stage, but in 2020 to 2021 the proportion was 43.8% (28 of 64) (Table 3 and Fig. 3)

Microbial Findings

Staphylococcus aureus was the most identified pathogen, accounting for 116 (27.8%) infections. Most of the early infections were caused by *S. aureus* (72 of 175, 41.1%), most chronic infections by coagulase-negative staphylococci (CNS) (25 of 92, 27.2%), and most common pathogens causing acute hematogenous PJIs were beta-hemolytic streptococci (22 of 151, 21.9%) (Tables 5 and 6).

The proportion of infections caused by CNS decreased from 25% (10 of 40) in 2008 to 2009 to 11.4% (8 of 70) in 2020 to 2021. However, the proportion of infections caused by *S. aureus* remained at the same level throughout the study period. The proportion of negative cultures increased slightly. In 2008 to 2009, 20% (8 of 45) of the infections were culture-negative, whereas the proportion had increased to 25.7% (18 of 70) in 2020 to 2021 (Table 7).

Discussion

To better understand the demographics and trends in the treatment of PJI of the knee, we analyzed all revision surgeries due to PJI performed at our institution between January 2008 and September 2021. The results revealed that the comorbidity burden among patients who had a PJI remained at the same level, with no clear trends. However, surgical strategies changed during the study period. For example, in addition to DAIR, 1-stage revision has

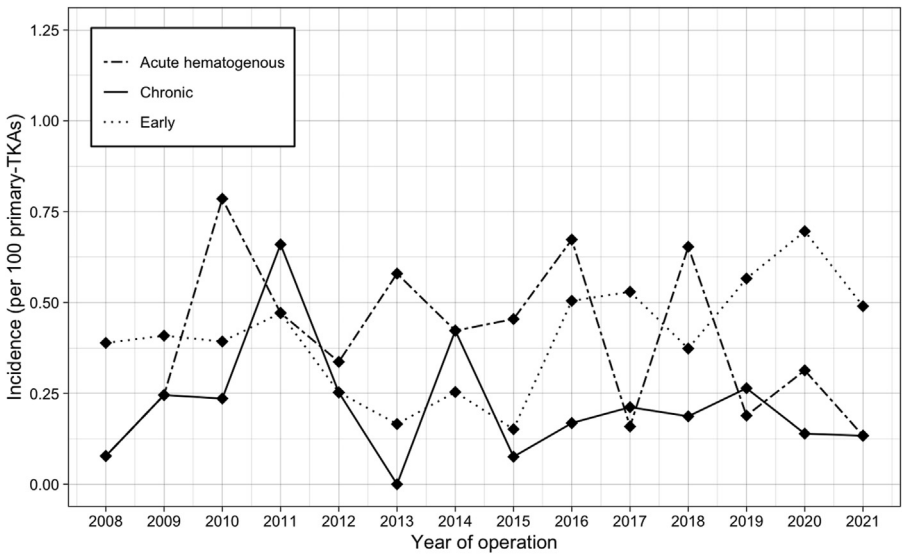

Fig. 2. Incidence of revision surgeries due to prosthetic joint infection at our institution stratified by the type of infection between 2008 and 2021.

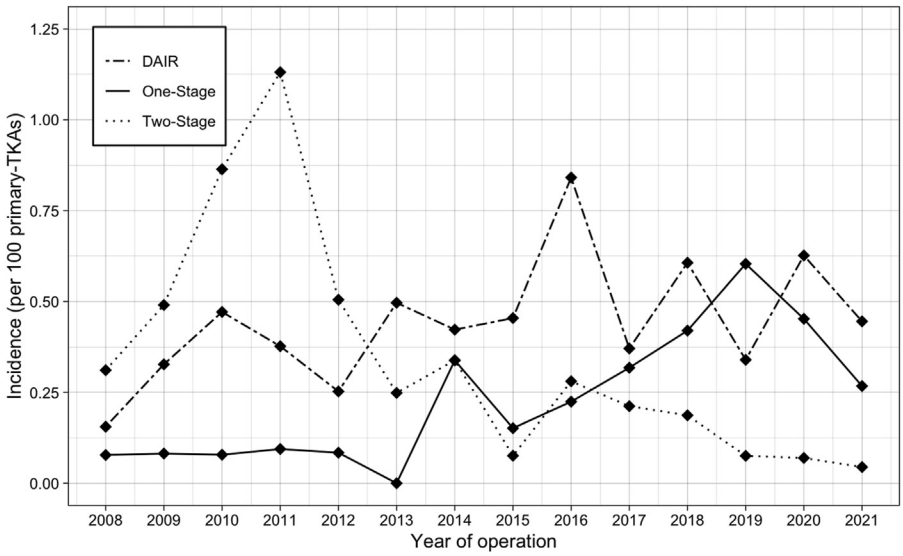

Fig. 3. Incidence of revision surgeries due to prosthetic joint infection at our institution stratified by the type of operation between 2008 and 2021.

become the most used strategy, and the proportion of 2-stage revisions has decreased remarkably. Furthermore, we found that there are rather large yearly variations in incidences, but with no clear trends. Interestingly, we also found that acute hematogenous PJIs are mostly caused by beta-hemolytic streptococci and not *S. aureus*.

Traditionally, 2-stage revision has been the gold standard for the treatment of PJI, especially for late infections [3,13]. However, recent studies have questioned the superiority of 2-stage revision compared to 1-stage revision [25,26]. During our study period, the proportion of 2-stage revisions decreased from over 50% to under 10%, whereas the proportion of 1-stage revisions performed increased from 12.1% to 43.8%. However, the proportion of DAIRs was over 30% for most of the study period, and it remained as the most performed surgical treatment. A similar increasing trend in 1-stage revisions in Germany between 2008 and 2021 has been reported by Rupp *et al.* [9]. In contrast to the findings of our study, they observed an increase in the proportion of 2-stage revisions and a decrease in the proportion of DAIRs. However, as they did not categorize infection types, it remains unclear whether there were any changes in infection types during the study period, which could have possibly affected the distribution of the surgical strategies.

Our findings can be partly explained by the adoption of the so called "1.5-stage revision", where the PJI is managed in a 1-stage manner with the retention of an articulating spacer, since this has been reported to be a reasonable method for treating PJI of the knee [16,27]. In addition, as our institution is a high-volume center, we currently prefer to perform 1-stage revision on as many patients as possible because there are less costs included than in 2-stage revisions [28].

Although an increase in the incidence of PJI of the knee has been reported [9,10], decreases in the incidence of PJI have also been reported [7,8]. However, as the demand for primary TKAs is rapidly increasing [29], the absolute number of early infections is expected to scale up accordingly. In the present study, we did not observe a remarkable increase in the incidence of PJI, but the yearly variation was large. Early infections were the most common infection type, which might be due to the increased number of primary TKAs performed at our institution. Indeed, the number of primary TKAs performed at our institution more than doubled between 2008 and 2020.

Table 5
Microbiological Results From Tissue Specimens Stratified by the Type of Infection.

Pathogen	All (n = 418)		Early (n = 175)		Acute Hematogenous (n = 151)		Chronic (n = 92)	
	N	%	N	%	N	%	N	%
Staphylococcus aureus	116	27.8	72	41.1	28	18.5	16	17.4
CNS	79	18.9	37	21.1	17	11.3	25	27.2
Streptococcus beta-hemolyticus	48	11.5	14	8	33	21.9	1	1.1
Other streptococcus species	11	2.6	4	2.3	6	4	1	1.1
Gram-negative aerobic	22	5.3	7	4	12	7.9	3	3.3
Enterococcus species	13	3.1	6	3.4	5	3.3	2	2.2
Anaerobic	8	1.9	4	2.3	2	1.3	2	2.2
Other	7	1.7	5	2.9	2	1.3	0	0
Negative culture	114	27.3	26	14.9	46	30.5	42	45.7

Infections are Classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms), and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms). Microbiological Findings From the Polymicrobial Infections (n = 29, 34 Additional Pathogens) are Included, and Therefore the Total N is Greater Than the Total N of the Surgeries Performed (n = 384). Corynebacterium Species (n = 4), Listeria Monocytogenes, Gemella Species and Kocuria Rhizophila are Included in the Other Group.
CNS, coagulase-negative staphylococci.

Table 6
Microbiological Results From Polymicrobial Infections (n = 29) Stratified by the Type of Infection.

Pathogen	All (n = 63)		Early (n = 50)		Acute Hematogenous (n = 6)		Chronic (n = 7)	
	N	%	N	%	N	%	N	%
Staphylococcus aureus	11	17.5	10	20	0	0	1	14.3
CNS	22	34.9	15	30	2	33.3	5	71.4
Streptococcus beta-hemolyticus	10	15.9	7	14	3	50	0	0
Other streptococcus species	4	6.3	2	4	1	16.7	1	14.3
Gram-negative aerobic	4	6.3	4	8	0	0	0	0
Enterococcus species	4	6.3	4	8	0	0	0	0
Anaerobic	3	4.8	3	6	0	0	0	0
Other	5	7.9	5	10	0	0	0	0

Infections are Classified as early (≤3 mo From the previous Surgery), Acute Hematogenous (>3 mo From the previous Surgery With <28 d of Symptoms), and Chronic (>3 mo From the previous Surgery With ≥28 d of Symptoms).
CNS, coagulase-negative staphylococci.

We observed no trends in the comorbidity burden of patients. This is a surprising finding since the number of comorbidities of primary TKA patients has been observed to be high, with an increasing trend [30]. Moreover, a decreasing trend in the prevalence of diabetes mellitus and rheumatoid arthritis was observed. However, as we did not analyze the specific risk factors for PJI after TKA, we can only state that the comorbidity burden of patients who have a PJI was approximately the same during our study period. In addition, the yearly variation was large due to the selection bias that the rare nature and small numbers of PJI can cause.

Previous studies have usually analyzed the microbiological findings of PJIs without stratifying them by joint [17–19]. However, as it has been reported that the microbiology might differ between joints, a joint-specific examination is warranted [31]. The proportion of PJIs caused by CNS decreased, but since CNS was the most common of the chronic infections and the proportion of chronic infections was approximately the same at the beginning and the end of the study period, this decrease might be due to a decrease among early or acute infections. Furthermore, the proportion of *S. aureus* was approximately 30% throughout the study period, which might reflect the steady proportions of early infections, as *S. aureus* has been reported to be the most common pathogen among early infections [17,18].

Surprisingly, acute hematogenous PJIs were commonly caused by beta-hemolytic streptococci and not *S. aureus*, even though both were common. Similar results were reported by Triffault-Fillit et al. who also reported that a higher number of acute hematogenous PJIs was caused by streptococci than by *S.aureus* [18]. The high proportion of streptococci's among acute PJIs might also be a knee-specific phenomenon since streptococcal knee PJIs have previously been associated with erysipelas or cellulitis of the knee [32].

The present study has several potential limitations that must be addressed. Due to the rare nature of PJI, our findings might be prone to selection bias, which is a common concern in PJI research. However, because we have a total of almost 400 patients, we believe the risk of selection bias has been minimized. Furthermore, as the same surgeons managed all the patients in the same institution, the potential risk was also as minimal as possible. We also analyzed the surgeries in 2-year admission groups, which served to reduce the risk of selection bias. Also, due to the retrospective nature of the study, we did not have access to accurate antimicrobial treatment history. Therefore, treatment may have started before surgery, and thus affected the results from the tissue specimens. Conversely, since the diagnosis of PJI does not require positive intraoperative cultures [20,33], we believe that this potential limitation did not affect the interpretation of our results. Another limitation of our study is that we did not have accurate access to information on those intraoperative factors that might have affected the decision on surgical technique, such as bone stock or soft tissue condition. However, as all patients were managed by the same surgeons at the same institution with similar guidelines, we believe that possible bias to our results was minimized. The strengths of this study were the large sample size with accurate records from our high-quality prospectively maintained data lake. In addition, the large sample size combined with the length of the study period made it possible to examine temporal trends in a single-center setting.

Table 7
Microbiological Results From Tissue Specimens During Our Study Period.

Pathogen	2008-09 (n = 40)		2010–11 (n = 54)		2012–13 (n = 47)		2014–15 (n = 57)		2016–17 (n = 66)		2018–19 (n = 84)		2020–21 (n = 70)	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Staphylococcus aureus	13	32.5	7	13	14	29.8	13	22.8	13	19.7	32	38.1	24	34.3
CNS	10	25	16	29.6	8	17	15	26.3	12	18.2	10	11.9	8	11.4
Streptococcus beta-hemolyticus	3	7.5	7	13	5	10.6	5	8.8	8	12.1	10	11.9	10	14.3
Other streptococcus species	1	2.5	1	1.9	1	2.1	3	5.3	2	3	2	2.4	1	1.4
Gram-negative aerobic	2	5	1	1.9	1	2.1	5	8.8	5	7.6	4	4.8	4	5.7
Enterococcus species	2	5	1	1.9	1	2.1	2	3.5	1	1.5	6	7.1	0	0
Anaerobic	1	2.5	4	7.4	2	4.3	0	0	0	0	0	0	1	1.4
Other	0	0	1	1.9	0	0	0	0	1	1.5	1	1.2	4	5.7
Negative culture	8	20	16	29.6	15	31.9	14	24.6	24	36.4	19	22.6	18	25.7

Microbiological Findings From the Polymicrobial Infections (n = 29, 34 Additional Pathogens) are Included, and Therefore the Total N is Greater Than the Total N of the Surgeries Performed (n = 384).
DAIR, debridement, antibiotics, and implant retention; CNS, coagulase-negative staphylococcus.

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In conclusion, the comorbidity burden among patients who have PJI remained at the same level with no clear trends. A DAIR was the most used treatment strategy, but the proportion of 1-stage revisions performed rose to almost the same level. The incidence of PJI varied between years, remaining relatively low at all times.

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References

[1] Premkumar A, Kolin DA, Farley KX, Wilson JM, McLawhorn AS, Cross MB, et al. Projected economic burden of periprosthetic joint infection of the hip and knee in the United States. J Arthroplasty 2021;36:1484–1489.e3. https://doi.org/10.1016/j.arth.2020.12.005.

[2] Sabah SA, Alvand A, Price AJ. Revision knee replacement for prosthetic joint infection: epidemiology, clinical outcomes and health-economic considerations. Knee 2021;28:417–21. https://doi.org/10.1016/j.knee.2020.12.024.

[3] Gehrke T, Alijanipour P, Parvizi J. The management of an infected total knee arthroplasty. Bone Joint J 2015;97-B(10 Suppl A):20–9.

[4] Kurtz SM, Ong KL, Lau E, Bozic KJ, Berry D, Parvizi J. Prosthetic joint infection risk after TKA in the medicare population. Clin Orthop Relat Res 2010;468:52–6. https://doi.org/10.1007/s11999-009-1013-5.

[5] Kurtz SM, Lau EC, Son M-S, Chang ET, Zimmerli W, Parvizi J. Are we winning or losing the battle with periprosthetic joint infection: trends in periprosthetic joint infection and mortality risk for the medicare population. J Arthroplasty 2018;33:3238–45. https://doi.org/10.1016/j.arth.2018.05.042.

[6] Huotari K, Peltola M, Jämsen E. The incidence of late prosthetic joint infections. Acta Orthop 2015;86:321–5. https://doi.org/10.3109/17453674.2015.1035173.

[7] Wang F-D, Wang Y-P, Chen C-F, Chen H-P. The incidence rate, trend and microbiological aetiology of prosthetic joint infection after total knee arthroplasty: a 13 years' experience from a tertiary medical center in Taiwan. J Microbiol Immunol Infect 2018;51:717–22. https://doi.org/10.1016/j.jmii.2018.08.011.

[8] Bozzo A, Ekhtiari S, Madden K, Bhandari M, Ghert M, Khanna V, et al. Incidence and predictors of prosthetic joint infection following primary total knee arthroplasty: a 15-year population-based cohort study. J Arthroplasty 2022;37:367–372.e1. https://doi.org/10.1016/j.arth.2021.10.006.

[9] Rupp M, Walter N, Lau E, Worlicek M, Kurtz SM, Alt V. Recent trends in revision knee arthroplasty in Germany. Sci Rep 2021;11:15479. https://doi.org/10.1038/s41598-021-94988-7.

[10] Chang C-H, Lee S-H, Lin Y-C, Wang Y-C, Chang C-J, Hsieh P-H. Increased periprosthetic hip and knee infection projected from 2014 to 2035 in Taiwan. J Infect Public Health 2020;13:1768–73. https://doi.org/10.1016/j.jiph.2020.04.014.

[11] Carender CN, Glass NA, DeMik DE, Elkins JM, Brown TS, Bedard NA. Projected prevalence of obesity in primary total hip arthroplasty: how big will the problem get? J Arthroplasty 2022;37:874–9. https://doi.org/10.1016/j.arth.2022.01.087.

[12] Lenguerrand E, Whitehouse MR, Beswick AD, Kunutsor SK, Foguet P, Porter M, et al. Risk factors associated with revision for prosthetic joint infection following knee replacement: an observational cohort study from England and Wales. Lancet Infect Dis 2019;19:589–600. https://doi.org/10.1016/S1473-3099(18)30755-2.

[13] Izakovicova P, Borens O, Trampuz A. Periprosthetic joint infection: current concepts and outlook. EFORT Open Rev 2019;4:482–94. https://doi.org/10.1302/2058-5241.4.180092.

[14] Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med 2004;351:1645–54. https://doi.org/10.1056/NEJMra040181.

[15] Srivastava K, Bozic KJ, Silverton C, Nelson AJ, Makhni EC, Davis JJ. Reconsidering strategies for managing chronic periprosthetic joint infection in total knee arthroplasty: using decision analytics to find the optimal strategy between one-stage and two-stage total knee revision. J Bone Joint Surg Am 2019;101:14–24. https://doi.org/10.2106/JBJS.17.00874.

[16] Hernandez NM, Buchanan MW, Seyler TM, Wellman SS, Seidelman J, Jiranek WA. 1.5-Stage exchange arthroplasty for total knee arthroplasty periprosthetic joint infections. J Arthroplasty 2021;36:1114–9. https://doi.org/10.1016/j.arth.2020.09.048.

[17] Benito N, Mur I, Ribera A, Soriano A, Rodríguez-Pardo D, Sorlí L, et al. The different microbial etiology of prosthetic joint infections according to route of acquisition and time after prosthesis implantation, including the role of multidrug-resistant organisms. J Clin Med 2019;8:673. https://doi.org/10.3390/jcm8050673.

[18] Triffault-Fillit C, Ferry T, Laurent F, Pradat P, Dupieux C, Conrad A, et al. Microbiologic epidemiology depending on time to occurrence of prosthetic joint infection: a prospective cohort study. Clin Microbiol Infect 2019;25:353–8. https://doi.org/10.1016/j.cmi.2018.04.035.

[19] Tai DBG, Patel R, Abdel MP, Berbari EF, Tande AJ. Microbiology of hip and knee periprosthetic joint infections: a database study. Clin Microbiol Infect 2022;28:255–9. https://doi.org/10.1016/j.cmi.2021.06.006.

[20] Diagnosis of periprosthetic joint infection. J Orthop Res 2014;32:S98–107. https://doi.org/10.1002/jor.22553.

[21] Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987;40:373–83. https://doi.org/10.1016/0021-9681(87)90171-8.

[22] Fillingham YA, Della Valle CJ, Suleiman LI, Springer BD, Gehrke T, Bini SA, et al. Definition of successful infection management and guidelines for reporting of outcomes after surgical treatment of periprosthetic joint infection: from the workgroup of the musculoskeletal infection society (MSIS). J Bone Joint Surg Am 2019;101:e69. https://doi.org/10.2106/JBJS.19.00062.

[23] Kapadia BH, Berg RA, Daley JA, Fritz J, Bhave A, Mont MA. Periprosthetic joint infection. Lancet 2016;387:386–94. https://doi.org/10.1016/S0140-6736(14)61798-0.

[24] von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Bull World Health Organ 2007;85:867–72. https://doi.org/10.2471/BLT.07.045120.

[25] Nguyen M, Sukeik M, Zahar A, Nizam I, Haddad FS. One-stage exchange arthroplasty for periprosthetic hip and knee joint infections. Open Orthop J 2016;10:646–53. https://doi.org/10.2174/1874325001610010646.

[26] van den Kieboom J, Tirumala V, Box H, Oganesyan R, Klemt C, Kwon Y-M. One-stage revision is as effective as two-stage revision for chronic culture-negative periprosthetic joint infection after total hip and knee arthroplasty. Bone Joint J 2021;103-B:515–21. https://doi.org/10.1302/0301-620X.103B.BJJ-2020-1480.R2.

[27] Siddiqi A, George NE, White PB, Szczech BW, Thompson JV, Etcheson JI, et al. Articulating spacers as a modified one-stage revision total knee arthroplasty: a preliminary analysis. Surg Technol Int 2018;32:239–48.

[28] Okafor CE, Nghiem S, Byrnes J. Is 2-stage septic revision worth the money? A cost-utility analysis of a 1-stage versus 2-stage septic revision of total knee arthroplasty. J Arthroplasty 2023;38:347–54. https://doi.org/10.1016/j.arth.2022.09.003.

[29] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Sureg Am 2007;89:780–5. https://doi.org/10.2106/JBJS.F.00222.

[30] O'Toole P, Maltenfort MG, Chen AF, Parvizi J. Projected increase in periprosthetic joint infections secondary to rise in diabetes and obesity. J Arthroplasty 2016;31:7–10. https://doi.org/10.1016/j.arth.2015.07.034.

[31] Preobrazhensky P, Bozhkova S, Kochish A, Tikhilov R, Kazemirsky A. Comparative analysis of pathogen structure in patients with PJI after primary total hip and knee arthroplasty. Arch Orthop Trauma Surg 2021;141:1963–9. https://doi.org/10.1007/s00402-021-04139-w.

[32] Wouthuyzen-Bakker M, Lora-Tamayo J, Senneville E, Scarbourough M, Ferry T, Uçkay I, et al. Erysipelas or cellulitis with a prosthetic joint in situ. J Bone Jt Infect 2018;3:222–5. https://doi.org/10.7150/jbji.25519.

[33] Palan J, Nolan C, Sarantos K, Westerman R, King R, Foguet P. Culture-negative periprosthetic joint infections. EFORT Open Rev 2019;4:585–94. https://doi.org/10.1302/2058-5241.4.180067.