The Journal of Arthroplasty xxx (2024) 1–8

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Outcomes of Debridement, Antibiotics, and Implant Retention in the Management of Infected Total Knee Arthroplasty: Analysis of 5,178 Cases From the National Australian Registry

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A R T I C L E I N F O

Article history:
Received 17 September 2024
Received in revised form
12 December 2024
Accepted 13 December 2024
Available online xxx

Keywords:
primary knee arthroplasty
periprosthetic joint infection
DAIR
revision
AOANJRR

A B S T R A C T

Background: Periprosthetic joint infection is a devastating and severe complication of total knee arthroplasty (TKA). The Australian Joint Registry reports an increasing number of debridement, antibiotics, and implant retention (DAIR) procedures, underscoring the need to comprehend outcomes for informed treatment decisions. This study aimed to determine the outcome of DAIR procedures, evaluate time since primary TKA, and identify patient-related factors associated with DAIR failure.

Methods: We conducted a national registry-based cohort study using data from 1999 to 2021. We included 8,642 revisions for infection, of which 5,178 were DAIR procedures (60%) predominantly performed within four weeks of primary surgery. We assessed the outcomes using Kaplan–Meier estimates and Cox proportional hazard models.

Results: Post-DAIR, the cumulative percent second revision cumulative percent revision in the DAIR cohort was 20% at year 1, increasing to 36% at year 17. Early DAIR procedures had a lower post-DAIR revision rate until three months after primary TKA. A DAIR performed within 2 weeks after primary TKA compared to three months had an hazard ratio [HR]: 0.74 (95% CI [confidence interval]: 0.62 to 0.88). After four weeks, the post-DAIR revision rate did not deteriorate and was similar for further time periods from the primary. Men had an age-adjusted HR of 1.28 (95% CI: 1.14 to 1.43, $P < 0.001$) for DAIR failure compared to women. There was a significantly higher HR for post-DAIR revision in patients younger than 75 years of age, compared to patients aged $\geq$ 75 years.

Conclusions: These findings underscore the critical influence of patient-related factors and the timing of DAIR treatment on the need for additional surgery. DAIR after four weeks had an increased risk of subsequent revision, and older women undergoing early DAIR interventions had more favorable

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2024.12.016.

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https://doi.org/10.1016/j.arth.2024.12.016

outcomes. Understanding these nuances aids in optimizing periprosthetic joint infection management strategies, offering insights for decision-making.

Periprosthetic joint infections (PJIs) are one of the most common, costly, and most devastating complications of total knee arthroplasty (TKA) [1–4]. The management of PJI necessitates surgical intervention, including debridement, antibiotics, and implant retention (DAIR) [5] or major component revision. A DAIR is considered a more benign surgical option, but has limitations. A DAIR is indicated for early postoperative PJI and late-acute PJI, but management recommendations are based on limited evidence [6]. The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) has identified the increasing use of DAIR for the management of PJI [7]. The projected increased demand for TKA combined with an increasing number of patients living with a prosthesis will be associated with an increasing burden of PJI revision procedures estimated to cost $1.85 billion in the United States in 2030 [8]. There is a cost advantage associated with DAIR procedures compared to more expensive revisions involving major component exchange [9,10]. Morbidity from major surgery is also less with DAIR compared to one- or two-stage revisions.

Understanding DAIR outcomes may guide treatment choices between DAIR or a major revision. Quantifying the outcomes of revision for PJI is challenging. Studies have primarily focused on short-term outcomes in small cohorts and from single institutions [11–13]. Success rates of DAIR for PJI are highly variable and range from 17 to 100% [14–24], with differences in the inclusion criteria, including pathogens and treatment protocols.

While the risks associated with acquiring a PJI are well described, the impact of these factors on DAIR outcomes is less clear. Several patient-related factors, including age, comorbidities, and duration of symptoms, are suggested to influence the success of DAIR [6,25,26]. The time since primary TKA has recently been identified as a prognostic factor [26,27]. There is a paucity of large-scale and nationwide studies investigating the survivorship of DAIR for TKA PJI, and none validate the influence of time since primary TKA. This study aimed to estimate the long-term outcome of DAIR procedures in TKA to study the patient-related factors associated with DAIR failures and to evaluate if the time since primary TKA influences the rate of DAIR failures.

Method and Patients

This study was a population-based, nationwide cohort study based on the AOANJRR.

Data Source

The AOANJRR commenced data collection on September 1, 1999, achieving complete national implementation by mid-2002. Following verification against health department data, checking of unmatched data, and subsequent retrieval of unreported procedures, the registry obtains an almost complete dataset (99.2%) of hip, knee, and shoulder arthroplasty in Australia.

The AOANJRR data are externally validated against patient-level data provided by all Australian state and territory health departments. A sequential, multilevel matching process is used to identify any missing data retrieved by contacting the relevant hospital. Each month, in conjunction with internal validation and data quality checks, all primary procedures are linked to any subsequent revision involving the same patient, joint, and side. Data are matched biannually with the Australian Government's National Death Index to obtain information on the date of death. The registry records patient demographics, including age, sex, and the surgeon-recorded diagnosis of primary and any subsequent revisions.

The AOANJRR commenced the American Society of Anesthesiologists (ASA) score collection in 2012 and has been recorded in 97.1% of knee procedures since then. Body mass index (BMI) has been collected since 2015 and recorded in 95.4% of all knee procedures.

The AOANJRR's revision diagnosis hierarchy defines a revision for infection as where the operating surgeon reported the diagnosis as infection. For this study, DAIR procedures were defined as revisions for infection that included the exchange of modular components only (polyethylene bearings).

Study Population

From the AOANJRR, we identified the study population of all primary TKA procedures performed for osteoarthritis between September 1, 1999, and December 31, 2022.

We excluded all patients not having had a revision and all first-time revisions not performed for infection. We identified 8,642 reoperations for infection from which the DAIR cohort was defined. Demographic data extracted from the AOANJRR included time from primary to revision, age, sex, ASA classification, and BMI. Reoperations for infection were binary registered as DAIR procedures or "other revisions for infection." We report on all-cause post-DAIR revision.

Data Analyses

Kaplan–Meier estimates of survivorship were used to report the time from the initial DAIR to the second revision, with censoring at the time of death and closure of the dataset on December 31, 2022. The unadjusted cumulative percent revision (CPR), with 95% confidence intervals (CI), was calculated using unadjusted pointwise Greenwood estimates for the standard error. Age- and sex-adjusted hazard ratios (HR) were calculated from Cox proportional hazard models to compare the rate of second revision for each risk factor.

The assumption of proportional hazards was checked analytically for each model. If the interaction between the predictor and the log of time was statistically significant in the standard Cox model, then a time-varying model was estimated. Time points were selected based on the most significant change in hazard, weighted by a function of events. Time points were iteratively chosen until the assumption of proportionality was met, and HRs were calculated for each time period. For the current study, if no time period was specified, the HR was calculated over the entire follow-up period.

Multivariable analyses adjusting for time since primary TKA, ASA score at the time of DAIR, BMI at DAIR, sex, and age at primary TKA were restricted to complete cases with no missing values for any covariate. Age at primary TKA, BMI at DAIR, and time since primary TKA were treated as continuous variables for adjustment. Nonlinearity in the effect of age at primary and time since the primary was accounted for by modeling with a restricted cubic spline with five knots and three knots for BMI. All tests were two-

Table 1
Summary of Primary TKA and First-Time Revision for Infection Demographics.

Variable	Primary TKA	DAIR 1st revision	Other septic 1st revision	Total
Follow-up years (Primary to 1st revision)				
Median (IQR)		0.8 (0.1, 3.2)	1.9 (0.8, 4.2)	1.3 (0.3, 3.7)
Follow-up years since procedure				
Median (IQR)	6.6 (3.2, 10.8)	2.6 (0.6, 5.9)	0.4 (0.2, 4.3)	6.5 (3.1, 10.8)
Age at procedure				
Median (IQR)	69 (62, 75)	70 (64, 77)	69 (62, 75)	69 (62, 75)
BMI at procedure[a]				
Median (IQR)	31.1 (27.5, 35.4)	31.2 (27.5, 36.4)	31.2 (27.2, 36.1)	31.1 (27.5, 35.4)
	n (%)	n (%)	n (%)	n (&)
Time since primary group				
≤ 4 weeks		867 (16.7)	48 (1.4)	915 (10.6)
> 4 weeks to ≤ 3 months		862 (16.6)	149 (4.3)	1,011 (11.7)
> 3 months to ≤ 1 year		1,053 (20.3)	828 (23.9)	1,881 (21.8)
> 1 year to ≤ 2 years		660 (12.7)	777 (22.4)	1,437 (16.6)
> 2 years		1,736 (33.5)	1,662 (48)	3,398 (39.3)
Age group at procedure in years				
< 55	56,572 (6.5)	302 (5.8)	255 (7.4)	57,129 (6.5)
55 to 64	228,998 (26.4)	1,126 (21.7)	854 (24.7)	230,978 (26.4)
65 to 74	346,261 (39.9)	2,013 (38.9)	1,417 (40.9)	349,691 (39.9)
≥ 75	235,282 (27.1)	1,737 (33.5)	938 (27.1)	237,957 (27.2)
Sex				
Men	384,418 (44.3)	3,265 (63.1)	2,001 (57.8)	389,684 (44.5)
Women	482,695 (55.7)	1,913 (36.9)	1,463 (42.2)	486,071 (55.5)
ASA score at procedure[b]				
ASA 1	28,633 (5.6)	66 (1.7)	36 (1.8)	28,735 (5.6)
ASA 2	276,607 (54.4)	1,101 (28.6)	696 (34.7)	278,404 (54.1)
ASA 3	198,228 (39)	2,271 (59)	1,169 (58.2)	201,668 (39.2)
ASA 4 or 5	5,317 (1)	410 (10.7)	106 (5.3)	5,833 (1.1)
BMI category at procedure[c]				
Underweight (< 18.50)	725 (0.2)	10 (0.4)	7 (0.5)	742 (0.2)
Normal (18.50 to 24.99)	43,343 (10.4)	309 (11.9)	196 (13.4)	43,848 (10.4)
Pre obese (25.00 to 29.99)	129,933 (31.3)	755 (29.1)	410 (27.9)	131,098 (31.2)
Obese class 1 (30.00 to 34.99)	128,563 (30.9)	740 (28.5)	414 (28.2)	129,717 (30.9)
Obese class 2 (35.00 to 39.99)	70,380 (16.9)	423 (16.3)	266 (18.1)	71,069 (16.9)
Obese class 3 (≥ 40.00)	42,623 (10.3)	361 (13.9)	174 (11.9)	43,158 (10.3)
Total	867,113	5,178	3,464	875,755

SD, standard deviation, IQR, interquartile range, ASA, American Society of Anesthesiologists, BMI, body mass index (kg/m^2); TKA, total knee arthroplasty.
[a] Excludes 456,123 procedures with unknown BMI at procedure.
[b] Excludes 361,115 procedures with unknown ASA score at procedure.
[c] Excludes 456,123 procedures with unknown BMI category at procedure.

tailed at 5% levels of significance. The BMI analysis was 80% powered to detect an HR of 1.08 comparing a 5-point variation of BMI from the mean assuming a normally distributed 2,600 procedures. Statistical analysis was performed using SAS software version 9.4 (SAS Institute Inc., Cary, North Carolina).

Ethical Approval

The Commonwealth of Australia approves the AOANJRR as a federal quality assurance activity under section 124X of the Health Insurance Act, 1973. All AOANJRR studies are conducted in accordance with ethical principles of research (the Helsinki Declaration II).

The DAIR procedure group included 5,178 patients who had a demographic profile similar to 3,464 patients in the "other infection revisions" group, except there was a large discrepancy between the age at primary TKA and years since primary TKA to revision (Table 1). Patients receiving DAIR tended to be older and undergo revision surgery sooner following the primary TKA compared to “other” septic revisions.

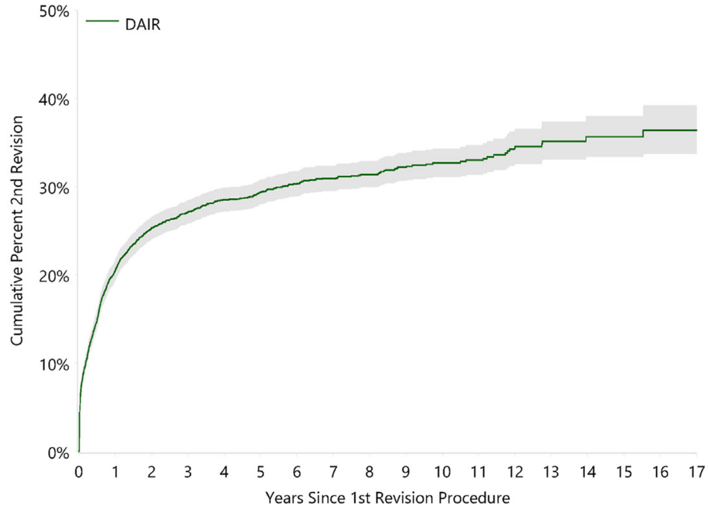
A DAIR was the most common treatment method overall for infection and represented 60% of the first-time revisions for PJI following primary TKA for osteoarthritis. A DAIR accounted for 95% of all reoperations for infection performed within four weeks of primary TKA, with a declining frequency down to 46% after 1 year and 51% after two years or more since primary TKA. A DAIR was performed in 65% of patients older than 75 years compared to 54 to 59% in the other age groups.

Results

During the study period, there were 1,399 post-DAIR revisions. The cumulative percent second revision (CPR) increased from 20.5% at 1 year (95% CI: 19.4 to 21.6) to 36.4% at 17 years (95% CI: 33.7 to 39.2, Figure 1). The most frequent type of post-DAIR revision was a major revision in 69.3% and a repeat DAIR in 25.9% of cases. The most common diagnosis for the post-DAIR revision was an infection, accounting for 87.8%, followed by loosening 5.4%, instability 1.6%, and pain 1.2% (Figure 2).

Risk Factors for Secondary Revisions after the First DAIR Revision

Early DAIR procedures (less than four weeks from primary TKA) had a lower post-DAIR revision rate than all other time periods. After four weeks, the post-DAIR revision rate was similar to the other time from primary periods investigated when adjusted for age and sex (overall test for time since primary effect $P < 0.001$). This is demonstrated in Figure 3. In multivariable analyses



CPR	1 Year	2 Years	3 Years	4 Years	5 Years
DAIR (95% CI)	20.5 (19.4, 21.6)	25.3 (24.1, 26.6)	27.1 (25.9, 28.4)	28.5 (27.2, 29.9)	29.3 (28.0, 30.7)

CPR	6 Years	7 Years	8 Years	9 Years	10 Years	11 Years
DAIR (95% CI)	30.3 (28.9, 31.7)	30.9 (29.5, 32.4)	31.4 (29.9, 32.9)	32.2 (30.7, 33.8)	32.7 (31.1, 34.3)	33.0 (31.4, 34.7)

CPR	12 Years	13 Years	14 Years	15 Years	16 Years	17 Years
DAIR (95% CI)	34.5 (32.6, 36.5)	35.1 (33.1, 37.3)	35.6 (33.4, 38.0)	35.6 (33.4, 38.0)	36.4 (33.7, 39.2)	36.4 (33.7, 39.2)

Figure 1. Cumulative percent post-DAIR (debridement, antibiotics, and implant retention) revision of primary TKA. DAIR, debridement, antibiotics, implant retention; CPR, cumulative percent second revision; CI, confidence interval.

adjusting for ASA and BMI, in addition to age and sex, DAIR procedures performed closest to primary TKA had lower post-DAIR revision rates until three months after the index TKA. DAIR procedures performed two weeks after the primary period had an HR of 0.74 (95% CI: 0.62 to 0.88) compared to four weeks, and DAIR procedures performed 1 month after the primary period had an HR of 0.86 (95% CI: 0.76 to 0.97) compared to three months. DAIR procedures performed at three months did not have a significantly different rate of post-DAIR revision compared to six, 12, and 24 months (Figure 4 and Table 2).

Men and younger patients were risk factors for post-DAIR revision (Table 2). Men had an age-adjusted HR of 1.28 (95% CI: 1.14 to 1.43, $P < 0.001$) compared to women (Figure 5). Younger patients had a greater rate of post-DAIR revision when compared with patients aged 75 years or older, with an HR of 1.28 (95% CI: 1.10 to 1.49, $P = 0.001$) for patients aged 65 to 74 years compared to patients older than 75 years in the entire period. Additionally, patients under 55 years of age compared to those older than 75 years had an HR of 2.41 (95% CI: 1.79 to 3.24, $P < 0.001$) for post-DAIR revision (Figure 6).

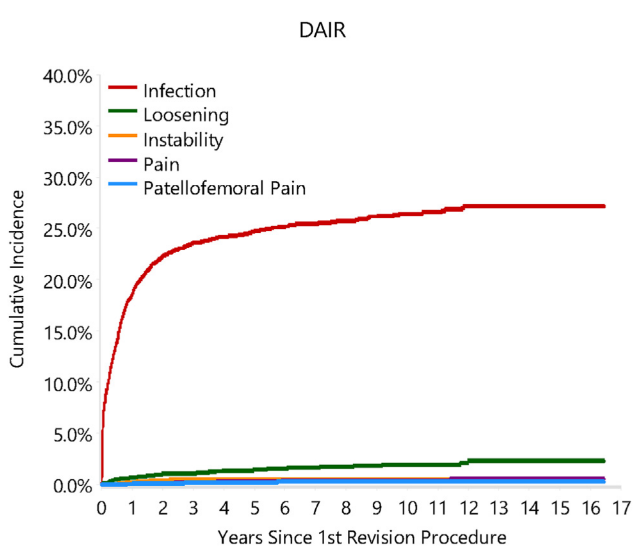


Figure 2. Cumulative incidence post-DAIR (debridement, antibiotics, and implant retention) revision diagnosis of primary TKA.

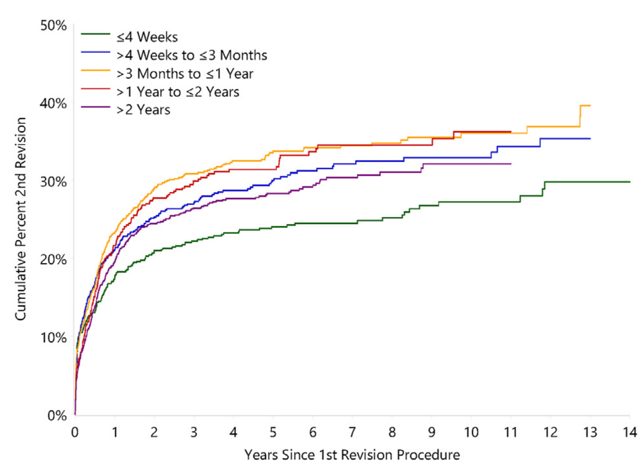


Figure 3. Cumulative percent post-DAIR (debridement, antibiotics, and implant retention) revision of primary TKA by the time since primary period.

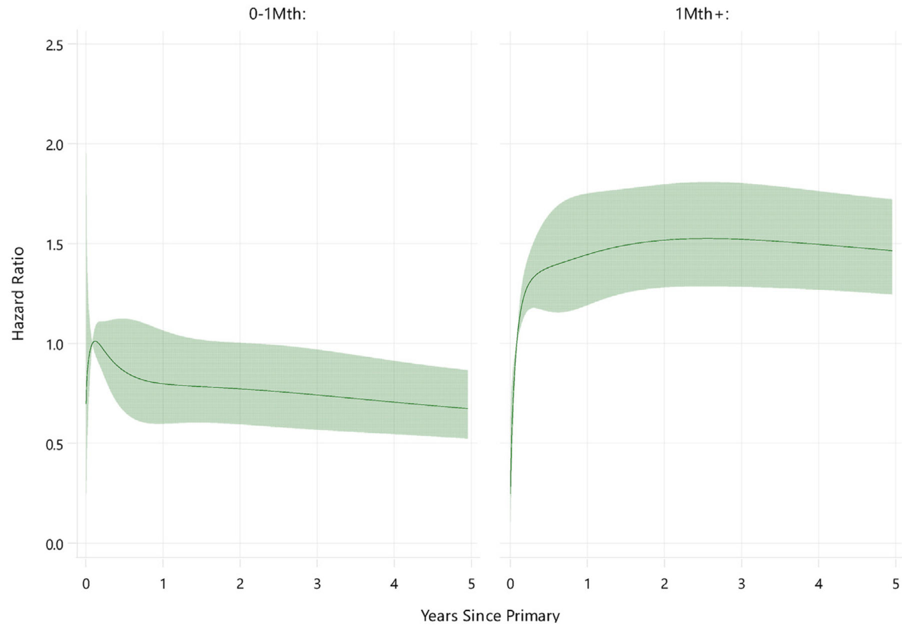


Figure 4. Hazard ratio of post-DAIR (debridement, antibiotics, and implant retention) revision compared to the time since primary period of four weeks in primary TKA. Adjusted for age and sex.

The BMI class was not significantly associated with the rate of post-DAIR revision after adjusting for sex and patient age at the time of the revision ($P = 0.375$). There was no significant association between ASA grade and post-DAIR revision rates when adjusted for age and sex but was significant with multivariable analysis HR 1.22 (95% CI: 1.02 to 1.46, $P = 0.028$).

Discussion

We report a large cohort of patients undergoing DAIR for the management of infected primary TKA utilizing a national registry. A DAIR was the most frequent revision strategy for all TKA revisions for infection and accounted for 60% of all first-time revisions for PJI and 95% of revisions for infection within four weeks from primary TKA. At 17 years, one-third of DAIR procedures had a post-DAIR revision, and the majority of DAIR failures occurred during the first year (20.5%). The most common diagnosis for repeat revision was infection. Revisions for other reasons, such as loosening, occurred later and accounted for only 12% of all post-DAIR revisions. Revisions after 4 weeks from primary TKA, men and younger patients all had similarly increased rates of post-DAIR revision. The ASA scores and BMI were not associated with repeat revision rates.

Infections managed with a DAIR procedure within four weeks of primary TKA had a more successful outcome compared to DAIR

Table 2
Summary of Multivariable Analysis of Revisions Following First-Time Debridement, Antibiotics, and Implant Retention (DAIR) Procedure for Infection.

Variable	N Total	Unrevised [Mean (SD) or n (%)]	Revised [Mean (SD) or n (%)]	Time Period	Unadjusted		Adjusted	
					HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Age at primary group	2,591	67.8 (9.3)	65.5 (9.3)			<0.001		<0.001
52.0 versus 67.0	.			Entire period:	1.40 (1.11, 1.77)	0.004	1.52 (1.21, 1.93)	<0.001
61.0 versus 67.0	.			Entire period:	1.24 (1.02, 1.51)	0.032	1.29 (1.06, 1.58)	0.010
67.0 versus 67.0	.			Entire period:	-	-	-	-
74.0 versus 67.0	.			Entire period:	1.03 (0.81, 1.30)	0.839	1.01 (0.80, 1.29)	0.913
82.0 versus 67.0	.			Entire period:	0.73 (0.55, 0.98)	0.038	0.73 (0.54, 0.99)	0.041
Sex	2,591	1942 (75.0%)	649 (25.0%)			<0.001		<0.001
Men	1,644	1,187 (72.2%)	457 (27.8%)	Entire period:	1.44 (1.22, 1.71)	<0.001	1.39 (1.17, 1.65)	<0.001
Women	947	755 (79.7%)	192 (20.3%)	Entire period:	-	-	-	-
ASA score at 1st revision	2,591	1942 (75.0%)	649 (25.0%)			0.465		0.028
ASA 1 to 2	765	573 (74.9%)	192 (25.1%)	Entire Period:	-	-	-	-
ASA 3 to 5	1826	1,369 (75.0%)	457 (25.0%)	Entire Period:	1.06 (0.90, 1.26)	0.465	1.22 (1.02, 1.46)	0.028
BMI at 1st revision	2,591	32.4 (7.6)	32.7 (6.7)			0.043		0.213
23.0 versus 31.2	.			Entire period:	0.77 (0.63, 0.95)	0.014	0.89 (0.72, 1.10)	0.281
27.5 versus 31.2	.			Entire period:	0.91 (0.84, 0.98)	0.016	0.96 (0.89, 1.04)	0.353
31.2 versus 31.2	.			Entire period:	-	-	-	-
36.4 versus 31.2	.			Entire period:	1.03 (0.97, 1.09)	0.312	0.98 (0.92, 1.05)	0.638
45.4 versus 31.2	.			Entire period:	0.91 (0.74, 1.11)	0.344	0.85 (0.69, 1.05)	0.129
Time since primary group	2,591	2.9 (4.1)	2.2 (3.1)			<0.001		<0.001
2 weeks versus 3 months	.			Entire period:	0.71 (0.54, 0.94)	0.016	0.71 (0.53, 0.94)	0.015
1 versus 3 months	.			Entire period:	0.85 (0.75, 0.96)	0.009	0.86 (0.76, 0.97)	0.014
3 versus 3 months	.			Entire period:	-	-	-	-
6 versus 3 months	.			Entire period:	1.03 (0.90, 1.18)	0.673	1.01 (0.88, 1.15)	0.906
1 year versus 3 months	.			Entire period:	1.03 (0.85, 1.25)	0.750	1.01 (0.83, 1.23)	0.916
2 years versus 3 months	.			Entire period:	1.01 (0.82, 1.24)	0.947	1.01 (0.82, 1.25)	0.928

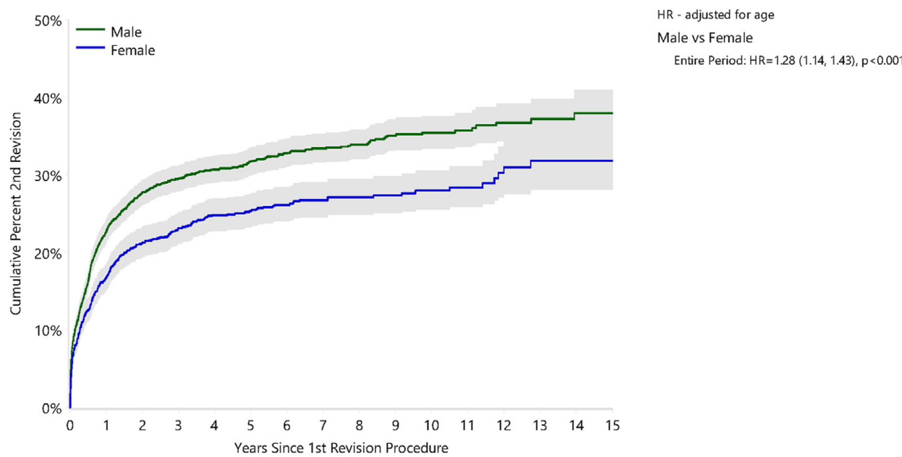


Figure 5. Cumulative percent post-DAIR (debridement, antibiotics, and implant retention) revision of primary TKA by sex.

procedures performed at all other time points investigated. DAIR procedures performed later than 4 weeks from primary TKA had a higher rate of post-DAIR revision. This rate of post-DAIR revision did not increase as time further elapsed after the primary procedure. This implies that acute infections and infections in subsequent time groups affect DAIR outcomes differently.

The Dutch registry observed no significant difference in rerevision comparing DAIR before four weeks to 5 to 12 weeks [28]. Conversely, Zhu et al. [26] and Rahardja et al. [27] reported early DAIR procedures for infection, which had a better success rate than DAIR procedures performed later than four weeks. They report a DAIR success of 67% when the revision was performed within the first 4 weeks from primary TKA but deteriorating results when DAIR is performed 2 years (37%) and 3 years (29%) after primary TKA. Our results indicated a 76% success rate for DAIR performed within the first 4 weeks after primary TKA. Beyond this 1-month period, implant survival showed a modest decline to 65%, which then stabilized over subsequent time intervals. Multivariable analysis demonstrated progressively worse outcomes as time from the primary TKA increased up to three months, with no significant deterioration in success rates observed thereafter. Success rates with DAIR in the Prosthetic joint Infection in Australia and New Zealand, Observational study were highest in early postimplant infections (110 of 160, 74%) and lower in late acute (132 of 267, 49%) and chronic (63 of 142, 44%) infections [29].

This study demonstrated that sex was associated with DAIR repeat revision rates, which is consistent with a recent meta-analysis from Choong et al. [30], who found women to have 29% lower odds of PJI treatment failure within 1 year postsurgery. Our study supports this significant result with a similar adjusted HR of 0.78 for DAIR failure in women patients compared to men.

The ASA score ranks patients for risk of adverse events during an operative procedure and is used as a surrogate for the underlying severity of systemic illness. The ASA scores have been reported to be as good a predictor of the risk of death within 1 year from primary arthroplasty surgery as other more complex comorbidity scores [31]. Higher ASA scores have also been associated with a greater risk of any revision within the first three months following primary THA [32], and our study found an association between higher ASA scores and increased failure of DAIR procedures. Our analysis of ASA scores only included patients treated since 2012 when ASA documentation was introduced in the AOANJRR, which excludes 361,115 procedures with an unknown ASA score at the time of surgery out of 867,113 procedures.

Methodological Considerations

The coverage of the AOANJRR is close to complete for primary TKA surgery, but registry studies have some inherent limitations [33]. A recent study evaluating the validity of AOANJRR through a

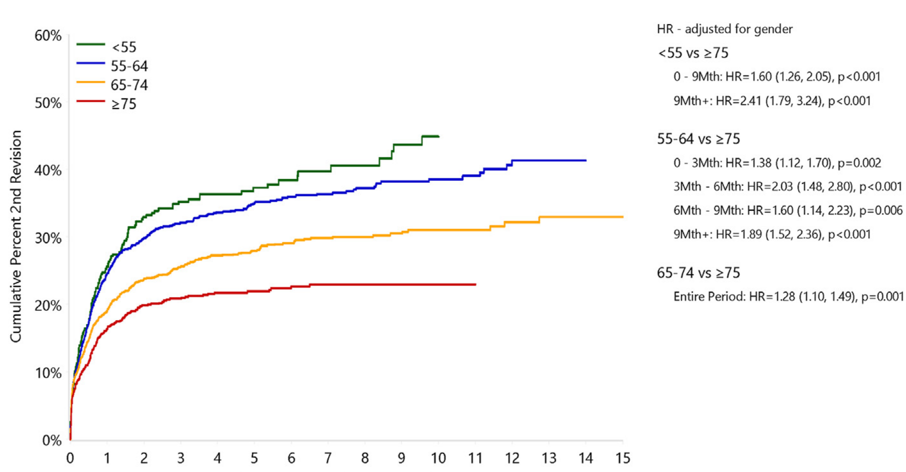


Figure 6. Cumulative percent post-DAIR (debridement, antibiotics, and implant retention) revision of primary TKA by the age at primary period.

large randomized controlled study with PJI diagnosis based on microbiological samples estimated that only 75% of confirmed PJIs are recorded in the AOANJRR [34]. In AOANJRR, patients are not monitored as rigorously as in a randomized controlled study, and the rate of some events may have been underestimated. It is also assumed that all reported PJIs are a correct diagnosis, not accounting for alterations to pathology reports and clinical misdiagnosis. The potential for inconsistencies in diagnosing PJIs will, in turn, impact results recorded in the registry, placing incorrect value on certain factors influencing DAIR outcomes, which could account for unexpected factors influencing prognosis in this study that contradict previous papers.

Our study underscores the nuanced influence of patient factors on the outcomes of DAIR procedures. While older patients, particularly women, demonstrated more favorable outcomes, there may be potential biases inherent in this observation. Surgeons may opt for conservative approaches, favoring antimicrobial suppression rather than repeat revision, in older patients who have perceived higher surgical risks. A systematic review from 2020 found limited and low-quality evidence when considering DAIR and suppressive antibiotic therapy failures [35]. Further studies with more stringent tier 1 definitions would help close the knowledge gap needed to consider individual patient characteristics and preferences for PJI management decisions.

Strengths

A major strength of this study was longitudinal data from a large sample size in a nationwide registry; this facilitated tracking the long-term effectiveness and safety of DAIR in treating PJIs and allowed for subset analyses. Collecting data from such a large sample size also reduced individual clinician and researcher bias. Ultimately, this study assessed the factors influencing DAIR's performance in treating PJI using real-world data and generalizable evidence.

Potential Limitations

There was limited information on important metrics that include patient factors, the infective organism, diagnostic pathology, and specifics of treatment options that are not recorded by the registry. Our definition of failure was based on the tier 1 and 2 International Consensus Meeting definition of infection control, which is the need for reoperation and/or revision [36]. Other studies [26,27] have used a more stringent tier 1 definition (infection control with no continued antibiotic therapy), which may account for some disparities in DAIR success rates, especially in older patients, but we assume both definitions would proportionally identify revision risks, such as time since primary period.

We used ASA as a surrogate for patient comorbidities, which is considered a valid mortality metric for large data sets [37]. BMI data were limited to patients since 2015, which excludes 456,123 patients who had an unknown BMI from a total of 867,113 procedures with our analysis powered to detect an HR of 1.08 between BMI classes. Furthermore, trends and paradigm shifts in surgical technique, perioperative care, the development of antibiotic-resistant species, and rehabilitation could have affected our results, as the study spans almost 25 years.

The influence of known confounding factors was mitigated through multivariable analyses but with some limitations in reported variables. There is potential for further unknown confounding variables other than those reported.

Conclusions

These findings have highlighted the burden of PJI following primary TKA and observed that DAIR was the most frequent surgical treatment used for 60% of first-time revisions for PJI in the last 2 decades. There were one-third of patients who ultimately required a post-DAIR revision. A DAIR performed within 1 month of primary TKA have more favorable outcomes for patients older than 75 years and women than their counterparts. When deciding on DAIR as an appropriate treatment option for PJI following primary TKA, the time since surgery and the patient's age, ASA score, and sex should be considered.

CRediT authorship contribution statement

Nicolai K. Kristensen: Writing – original draft, Validation, Investigation, Formal analysis. **Stuart A. Callary:** Writing – review & editing, Supervision, Conceptualization. **Renjy Nelson:** Writing – review & editing, Supervision. **Dylan Harries:** Writing – review & editing, Validation, Supervision, Investigation, Formal analysis, Data curation. **Michelle Lorimer:** Writing – review & editing, Validation, Investigation, Formal analysis, Data curation. **Paul Smith:** Writing – review & editing, Conceptualization. **David Campbell:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Formal analysis, Conceptualization.

Acknowledgments

We thank the AOANJRR staff for their assistance with the data and all the orthopaedic surgeons, hospitals, and patients whose data made this work possible.

References

[1] Roberts RR, Hota B, Ahmad I, Scott 2nd RD, Foster SD, Abbasi F, et al. Hospital and societal costs of antimicrobial-resistant infections in a Chicago teaching hospital: implications for antibiotic stewardship. Clin Infect Dis 2009;49:1175–84.

[2] Koh CK, Zeng I, Ravi S, Zhu M, Vince KG, Young SW. Periprosthetic joint infection is the main cause of failure for modern knee arthroplasty: an analysis of 11,134 knees. Clin Orthop Relat Res 2017;475:2194–201.

[3] National Joint Registry for England, W.a.N.I. 11th Annual Report. England, Wales and Northern Ireland: National Joint Registry; 2014. https://www.hqip.org.uk/wp-content/uploads/2018/02/national-joint-registry-11th-annual-report-2014.pdf. [Accessed 3 January 2025].

[4] Manning L, Metcalf S, Clark B, Robinson JO, Huggan P, Luey C, et al. Clinical characteristics, etiology, and initial management strategy of newly diagnosed periprosthetic joint infection: a multicenter, prospective observational cohort study of 783 patients. Open Forum Infect Dis 2020;7:ofaa068.

[5] Qasim SN, Swann A, Ashford R. The DAIR (debridement, antibiotics and implant retention) procedure for infected total knee replacement - a literature review. SICOT J 2017;3:2.

[6] Osmon DR, Berbari EF, Berendt AR, Lew D, Zimmerli W, Steckelberg JM, et al. Diagnosis and management of prosthetic joint infection: clinical practice guidelines by the Infectious Diseases Society of America. Clin Infect Dis 2013;56:e1–25.

[7] Australian Orthopaedic Association National Joint Replacement Registry. Hip, Knee & Shoulder Arthroplasty: 2023 Annual Report. Adelaide, Australia: Australian Orthopaedic Association National Joint Replacement Registry; 2023.

[8] 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.

[9] Merollini KM, Crawford RW, Graves N. Surgical treatment approaches and reimbursement costs of surgical site infections post hip arthroplasty in Australia: a retrospective analysis. BMC Health Serv Res 2013;13:91.

[10] Puhto T, Puhto AP, Vielma M, Syrjälä H. Infection triples the cost of a primary joint arthroplasty. Infect Dis (Lond) 2019;51:348–55.

[11] McPherson EJ, Woodson C, Holtom P, Roidis N, Shufelt C, Patzakis M. Periprosthetic total hip infection: outcomes using a staging system. Clin Orthop Relat Res 2002:8–15.
[12] Choi HR, Kwon YM, Freiberg AA, Malchau H. Comparison of one-stage revision with antibiotic cement versus two-stage revision results for infected total hip arthroplasty. J Arthroplasty 2013;28(8 Suppl):66–70.
[13] Fischbacher A, Borens O. Prosthetic-joint infections: mortality over the last 10 years. J Bone Jt Infect 2019;4:198–202.
[14] Zimmerli W, Widmer AF, Blatter M, Frei R, Ochsner PE. Role of rifampin for treatment of orthopedic implant-related staphylococcal infections: a randomized controlled trial. Foreign-Body Infection (FBI) Study Group. JAMA 1998;279:1537–41.
[15] Tattevin P, Crémieux AC, Pottier P, Huten D, Carbon C. Prosthetic joint infection: when can prosthesis salvage be considered? Clin Infect Dis 1999;29:292–5.
[16] Laffer RR, Graber P, Ochsner PE, Zimmerli W. Outcome of prosthetic knee-associated infection: evaluation of 40 consecutive episodes at a single centre. Clin Microbiol Infect 2006;12:433–9.
[17] Marculescu CE, Berbari EF, Hanssen AD, Steckelberg JM, Harmsen SW, Mandrekar JN, et al. Outcome of prosthetic joint infections treated with debridement and retention of components. Clin Infect Dis 2006;42:471–8.
[18] Chiu FY, Chen CM. Surgical debridement and parenteral antibiotics in infected revision total knee arthroplasty. Clin Orthop Relat Res 2007;461:130–5.
[19] Burger RR, Basch T, Hopson CN. Implant salvage in infected total knee arthroplasty. Clin Orthop Relat Res 1991:105–12.
[20] Brandt CM, Sistrunk WW, Duffy MC, Hanssen AD, Steckelberg JM, Ilstrup DM, et al. Staphylococcus aureus prosthetic joint infection treated with debridement and prosthesis retention. Clin Infect Dis 1997;24:914–9.
[21] Walkay S, Wallace DT, Balasubramaniam VSC, Maheshwari R, Changulani M, Sarungi M. Outcomes of debridement, antibiotics and implant retention (DAIR) for periprosthetic joint infection in a high-volume arthroplasty centre. Indian J Orthop 2022;56:1449–56.
[22] Toh RX, Yeo ZN, Liow MHL, Yeo SJ, Lo NN, Chen JY. Debridement, antibiotics, and implant retention in periprosthetic joint infection: what predicts success or failure? J Arthroplasty 2021;36:3562–9.
[23] Grammatopoulos G, Kendrick B, McNally M, Athanasou NA, Atkins B, McLardy-Smith P, et al. Outcome following debridement, antibiotics, and implant retention in hip periprosthetic joint infection-an 18-year experience. J Arthroplasty 2017;32:2248–55.
[24] Kildow BJ, Patel SP, Otero JE, Fehring KA, Curtin BM, Springer BD, et al. Results of debridement, antibiotics, and implant retention for periprosthetic knee joint infection supplemented with the use of intraosseous antibiotics. Bone Joint J 2021;103-B(6 Supple A):185–90.
[25] Kuiper JW, Vos SJC, Saouti R, Vergroesen DA, Graat HCA, Debets-Ossenkopp YJ, et al. Prosthetic joint-associated infections treated with DAIR (debridement, antibiotics, irrigation, and retention): analysis of risk factors and local antibiotic carriers in 91 patients. Acta Orthop 2013;84:380–6.
[26] Zhu MF, Kim K, Cavadino A, Coleman B, Munro JT, Young SW. Success rates of debridement, antibiotics, and implant retention in 230 infected total knee arthroplasties: implications for classification of periprosthetic joint infection. J Arthroplasty 2021;36:305–10. e1.
[27] Rahardja R, Zhu M, Davis JS, Manning L, Metcalf S, Young SW. Success of debridement, antibiotics, and implant retention in prosthetic joint infection following primary total knee arthroplasty: results from a prospective multicenter study of 189 cases. J Arthroplasty 2023;38(7 Suppl 2):S399–404.
[28] van der Ende B, van Oldenrijk J, Reijman M, Croughs PD, van Steenbergen LN, Verhaar JAN, et al. Timing of debridement, antibiotics, and implant retention (DAIR) for early post-surgical hip and knee prosthetic joint infection (PJI) does not affect 1-year re-revision rates: data from the Dutch Arthroplasty Register. J Bone Jt Infect 2021;6:329–36.
[29] Davis JS, Metcalf S, Clark B, Robinson JO, Huggan P, Luey C, et al. Predictors of treatment success after periprosthetic joint infection: 24-month follow up from a multicenter prospective observational cohort study of 653 patients. Open Forum Infect Dis 2022;9:ofac048.
[30] Choong AL, Shadbolt C, Choong E, Spelman T, Muñoz-Mahamud E, Lora-Tamayo J, et al. The impact of sex on the outcomes of prosthetic joint infection treatment with debridement, antibiotics and implant retention: a systematic review and individual patient data meta-analysis. J Am Acad Orthop Surg Glob Res Rev 2022;6.
[31] Peersman G, Laskin R, Davis J, Peterson MGE, Richart T. ASA physical status classification is not a good predictor of infection for total knee replacement and is influenced by the presence of comorbidities. Acta Orthop Belg 2008;74:360–4.
[32] Ferguson RJ, Silman AJ, Combescure C, Bulow E, Odin D, Hannouche D, et al. ASA class is associated with early revision and reoperation after total hip arthroplasty: an analysis of the Geneva and Swedish Hip Arthroplasty Registries. Acta Orthop 2019;90:324–30.
[33] Varnum C, Pedersen AB, Gundtoft PH, Overgaard S. The what, when and how of orthopaedic registers: an introduction into register-based research. EFORT Open Rev 2019;4:337–43.
[34] Sinagra ZP, Davis JS, Lorimer M, de Steiger RN, Graves SE, Yates P, et al. The accuracy of reporting of periprosthetic joint infection to the Australian orthopaedic association national joint replacement registry. Bone Jt Open 2022;3:367–73.
[35] Malahias MA, Gu A, Harris EC, Adriani M, Miller AO, Westrich GH, et al. The role of long-term antibiotic suppression in the management of peri-prosthetic joint infections treated with debridement, antibiotics, and implant retention: a systematic review. J Arthroplasty 2020;35:1154–60.
[36] Abblitt WP, Ascione T, Bini S, Bori G, Brekke AC, Chen AF, et al. Hip and knee section, outcomes: proceedings of international Consensus on orthopedic infections. J Arthroplasty 2019;34:S487–95.
[37] Penfold CM, Whitehouse MR, Blom AW, Judge A, Wilkinson JM, Sayers A. A comparison of comorbidity measures for predicting mortality after elective hip and knee replacement: a cohort study of data from the National Joint Registry in England and Wales. PLoS One 2021;16:e0255602.

Appendix

Supplementary Table S1
Yearly Cumulative Percent post-DAIR (debridement, antibiotics, and implant retention) Revision of Primary Total Knee Arthroplasty by Age at Primary.

CPR	1 Year	2 Years	3 Years	4 Years	5 Years
<55	25.5 (21.6, 30.1)	32.9 (28.4, 37.8)	35.2 (30.6, 40.2)	36.3 (31.6, 41.4)	37.2 (32.5, 42.5)
55 to 64	24.5 (22.4, 26.9)	29.8 (27.4, 32.3)	32.1 (29.6, 34.7)	33.6 (31.1, 36.2)	34.9 (32.3, 37.6)
65 to 74	19.0 (17.3, 20.8)	23.7 (21.8, 25.7)	25.6 (23.6, 27.7)	27.2 (25.1, 29.4)	27.9 (25.8, 30.2)
≥75	16.3 (14.3, 18.5)	19.9 (17.6, 22.3)	20.8 (18.6, 23.3)	21.7 (19.4, 24.3)	21.9 (19.5, 24.5)
CPR	**6 Years**	**7 Years**	**8 Years**	**9 Years**	**10 Years**
<55	38.3 (33.4, 43.7)	39.7 (34.6, 45.2)	40.5 (35.3, 46.3)	43.7 (37.7, 50.2)	44.8 (38.6, 51.6)
55 to 64	35.9 (33.3, 38.8)	36.3 (33.6, 39.1)	37.2 (34.4, 40.1)	38.2 (35.3, 41.2)	38.5 (35.6, 41.6)
65 to 74	29.0 (26.9, 31.3)	29.8 (27.5, 32.2)	30.0 (27.7, 32.4)	30.4 (28.1, 32.9)	31.0 (28.5, 33.6)
≥75	22.4 (19.9, 25.0)	22.9 (20.4, 25.7)	22.9 (20.4, 25.7)	22.9 (20.4, 25.7)	22.9 (20.4, 25.7)

CPR, cumulative percent revision.