Review Article

Contemporary outcomes of debridement, antibiotics and implant retention in knee arthroplasty

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Abstract: Periprosthetic joint infection (PJI) is a major complication after knee arthroplasty, with approximately a quarter of knee arthroplasty revisions citing PJI as an indication. With the demand for knee arthroplasty predicted to increase, coupled with a lack of evidence for decreasing PJI risk, an appreciation of the burdens of PJI on both patients and health care systems is vital. Patients with PJI can experience a reduced quality of life as well as increased morbidity, whilst the management of PJI has significant economic implications. Surgical options include debridement, antibiotics and implant retention (DAIR), single-stage revision, two-stage revision and salvage procedures. DAIR involves the systematic debridement of all infected and unhealthy tissues coupled with directed antibiotic therapy, with definitive infection clearance the objective. In contrast to single- and two-stage revision procedures for PJI, DAIR does not involve the removal of fixed implants, with only modular components exchanged. Potential benefits of DAIR include reduced tissue destruction, reduced morbidity and reduced healthcare burdens, but with a higher reinfection risk compared to staged revision techniques, and utility largely restricted to acute bacterial PJI. A review of contemporary DAIR outcomes is of value given advances in the understanding of PJI biology; the development of consensus-based definitions for PJI diagnosis and treatment outcomes; and evolution of DAIR indications and technique. This review discusses outcomes of DAIR for knee PJI, published over the last two decades.

Keywords: Knee; arthroplasty; infection; periprosthetic joint infection (PJI); debridement; antibiotics and implant retention; debridement, antibiotics and implant retention (DAIR)

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Introduction

Periprosthetic joint infection (PJI) is a significant complication following knee arthroplasty. PJI involves the establishment of bacterial (the majority) or fungal infection of a prosthetic joint, and can occur at any time following implantation. The risk of PJI after primary knee arthroplasty is relatively low, ranging from 1–4%, and increasing to 8–10% for revision cases (1–3). As a reason for revision surgery, however, PJI is the indication in 20–25% of cases (4,5). Given the predicted increase in demand for knee arthroplasty, and a lack of evidence of decreasing infection risk, PJI represents a significant and ongoing challenge in modern orthopaedics (6-8).

PJI has a significant impact on patients' quality of life and morbidity; with pain, reduced function, systemic sepsis, poor cosmesis, multiple surgeries and increased mortality all potential consequences (9,10). Treatment of PJI also places a significant burden on health care systems. From an economic perspective, revision of an infected

knee arthroplasty is estimated to cost £30,000/revision, and predicted hospital costs of $1.6 billion for 2020 in the USA (2,11). A recent report from Finland provides further insight, with the excess cost of debridement, antibiotics and implant retention (DAIR) found to be €12,800 *vs.* €44,600 for a two-stage revision (hip and knee procedures combined) (12).

Contemporary management of PJI has built upon improved consensus on what features define PJI and the behaviour of causative organisms on prosthetic materials. The most widely accepted definition of PJI is provided by the Musculoskeletal Infection Society (MSIS) criteria, originally proposed in 2011, and updated at International Consensus Meetings (most recently in 2018) (13,14). The investigation and reporting of outcomes for PJI management has likely benefited, with a reduction in heterogeneity as to what constitutes an infected knee prosthesis. From a mechanistic perspective, advances have been made in understanding how organisms adhere and interact with artificial materials. In particular, the bacterial formation of, behaviour in and resistance mechanisms provided by biofilms are of particular interest. Given the majority of PJIs are caused by biofilm producing organisms this knowledge has contributed to the development of management schema. For a review of biofilms in PJI, readers are directed to a 2020 review by Shoji *et al.* (15).

In the setting of acute PJI, DAIR belongs to a spectrum of surgical treatment options, with single-stage and two-stage revision representing increasing levels of intervention and greater morbidity. DAIR comprises the thorough debridement and irrigation of the soft tissues, exchange of modular components (polyethylene trays, axes, bushes etc.) but the primary femoral, tibial, and patellar components are retained. This is combined with a period of antibiotics with good bone bioavailability, with the aim of infection eradication. The potential benefits of DAIR over a formal revision procedure are reduced tissue damage and greater functional outcomes (16,17). Outcomes for DAIR have been reported since the 1980s, with highly variable levels of treatment success. Some of this variability is likely secondary to heterogeneity in PJI definition, evolving surgical techniques and varied definitions of treatment 'success' over the years. As such, a review of modern DAIR outcomes is of value in patient counselling and treatment decisions.

Details regarding the diagnosis of PJI, indications, contraindications and surgical technique of DAIR are described elsewhere in this issue. The objective of this article is to review the contemporary outcomes of DAIR in the management of knee PJI over the last two decades.

DAIR in total knee arthroplasty

The evidence base for outcomes after DAIR in TKA PJI predominantly consists of cohort studies, of which most are retrospective, with small patient numbers and short follow-up. Kunutsor *et al.*'s meta-analysis of DAIR for PJI included 28 studies in which patients were treated from the year 2000 onwards. Of these 28 studies, 20 reported outcomes for less than 100 patients and only 2 had follow-up times greater than 5 years (18). As of yet, there are no randomised controlled studies reporting the outcome of DAIR in comparison to other treatment modalities.

DAIR success rate and PJI eradication

The most commonly reported outcome for DAIR studies is 'treatment success', but with wide variation in what constitutes failure and time points used. However, as with the definition of PJI, there have been advances in reaching a consensus definition. Diaz-Ledezma *et al.* published the results of an international Delphi method in 2013, defining a successfully treated PJI, and what constitute mid-term (>5 years) and long-term (>10 years) results (19).

Kunutsor *et al.*'s meta-analysis provides a valuable estimate of outcomes for DAIR, and included studies published prior to May 2017. The summary estimate, across all studies of knee DAIR, for infection control was 52.6% (95% CI: 45.10–60.10%). Furthermore, subgroup analysis of outcomes of knee DAIR by time period demonstrated a non-significant difference, with outcomes for studies prior to 2,000 having an infection control rate of 46.0% (95% CI: 30.9–61.5%) *vs.* 56.0% (95% CI: 45.7–66.1%) for studies from 2000 to 2017 (18). A search for reports of outcomes of knee DAIR published since this period yielded few additional results, but with treatment success rates in keeping with this meta-analysis (*Table 1*). Qu *et al.*'s pooled analysis of 1,266 cases of acute PJI demonstrated an overall success rate of 57.1% (18 of the included 33 studies included patients treated patient prior to 2000) (20). Iza *et al.* retrospectively analysed 26 acute post-operative and acute haematogenous knee PJI managed with DAIR. At a mean follow-up of 3.4 years 77% of patients were infection free, with acute post-operative infections having better success than acute haematogenous

Table 1 Treatment success after DAIR for PJI

Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Outcomes	Other comments
Kunutsor *et al*., 2018, UK	Meta-analysis	Studies prior to May 2017	Mixed	DAIR for knee PJI prior to year 2000 (n=377); DAIR for knee PJI 2000 to 2017 (n=299)	Mixed	Infection control rates provided as % with 95% CI: <2000: 46.00% (30.90–61.50%); ≥2000: 56.00% (45.70–66.10%)	Includes acute post-operative, acute haematogenous and chronic PJI; definition of 'treatment success' varies by study. Article includes multiple other comparisons. Not a statistically significant difference in treatment success
Qu *et al*., 2019, China	Meta-analysis	Studies Prior to Jan 2018	Mixed	1,266 pooled cases	Mixed	Overall treatment success rate of 57.11% (95% CI: 54.4–59.8%)	Similar to above comments regarding PJI type and outcome definition
Chang *et al*., 2020, Republic of Korea	Retrospective cohort	2012 to 2013	Acute PJI after primary TKA.	10 knees	Median 24 (IQR 14–29) months	Overall treatment success of 78%	Treatment failure defined as requirement for long term antibiotics or further surgery for infection. Modified DAIR using antibiotic loaded cemented beads
Leta *et al*., 2019, Norway	Registry cohort	1994 to 2016	Not stated	329 DAIRs	Mean 5.1 (range, 0.01–21.9) years (entire study cohort)	22.2% revised for any reason; 19.1% revised for infection; 5-year KM survival for any cause: 79% (95% CI: 74.3–83.7%)	End-point of revision only (all cause and for infection)
Kim *et al*., 2019, New Zealand	Retrospective cohort	2000 to 2015	Not stated, but included 'all patients with first episode of PJI'	228 with DAIR as first treatment	Not reported	Overall treatment success 59.2%	Study focus was comparison of outcomes between 2SR and 2SR after failed DAIR; DAIR success rate obtained from report data
Iza *et al*., 2019, Spain	Retrospective cohort	2004 to 2016	Post-operative & acute haematogenous PJI with symptoms <3 weeks	26 patients	Mean 3.3 (range, 1 to 12) years	Overall treatment success of 77%	Treatment success defined as 'absence of infectious symptoms, normalization of inflammation markers, free of antibiotic therapy, without need for prosthetic replacement, and minimum follow-up of 1 year'; used international consensus criteria
Ottensen *et al*., 2018, Denmark	Retrospective cohort	2008 to 2013	All PJI after primary TKA treated with DAIR	58 patients	Minimum 2 years	Overall treatment success of 84%	PJI defined using MSIS criteria. Mixed types not specified; success: 'no further antibiotic treatment and no further revision surgery 2 years after DAIR'
Urish *et al*., 2018, United States	Retrospective cohort	2005 to 2015	Not stated.	216 knees	Median 13.5 (IQR 14.4–67.0) months	Overall treatment success of 49.5%; Probability of failure at 4 years: 57.4% (95% CI: 50.0–65.2%)	PJI cases identified using ICD-9 codes and modified MSIS criteria applied; failure defined as any further surgical procedure on knee (exclusions in report)

Table 1 (*continued*)

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Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Outcomes	Other comments
Narayanan *et al*., 2018, United States	Retrospective cohort	2009 to 2017	Acute and chronic PJI.	55 patients	Mean 2.5 years	Overall treatment success of 60%	Modified MSIS used to define PJI. Failure defined as need for additional surgical interventions with minimum 1-year follow-up
Bene *et al*., 2018, United States	Retrospective cohort	2004 to 2012	Acute PJI (<4 weeks of symptoms after primary TKA)	76 patients	Mean 3.5 (range, 0.1 to 9.7) years	Overall treatment success of 72.4%	PJI defined using MSIS criteria. Re-operation for infection as endpoint
Duffy *et al*., 2018, UK	Retrospective cohort	2008 to 2015	Mixed PJI	59 patients	Median 2.25 (IQR 1.58) years	Overall treatment success of 69%	PJI defined using international consensus criteria; failure endpoints were unscheduled surgery, death related to infection or requirement for long term antibiotics (all in first 12 months)
Weston *et al*., 2018, United States	Retrospective cohort	2000 to 2014	Acute post-operative and acute haematogenous (<4 weeks symptoms)	134 knees	Mean 5.0 (range, 2.1 to 13 years) after exclusions for death and losses to follow-up	5-year survival rates with 95% CI: infection: 34% (25–42%); component removal: 29% (20–37%)	PJI defined using MSIS. All patients received suppressive antibiotics post DAIR; primary outcomes included further infection, removal of components and death
Son *et al*., 2017, Korea	Retrospective cohort	2010 to 2014	PJI within 4 weeks of primary TKA, or acute haematogenous with ≤5 days symptoms	25 patients	Mean 29.4 (range, 24 to 35) months	Overall treatment success of 88%	Mixed PJI definition criteria (MSIS used for cases 2012 onwards); failure defined as death whilst on antibiotics, need for ongoing antibiotics, or need for further surgery

TKA, total knee arthroplasty; PJI, periprosthetic joint infection; DAIR, debridement, antibiotics and implant retention; CI, confidence interval; KM, Kaplan Meier.

(93% *vs*. 58%) (21). Ottesen *et al*. published an overall success rate after DAIR for knee PJI of 84% in a series of 58 patients treated between 2008 and 2013, with a minimum 2-year follow-up. A retrospective multicentre observational study of 216 knee DAIRs performed in the United States between 2005 and 2015 found a lower success rate, treatment failure in 51% (90% of failures occurred within the first year) (22). Narayanan *et al*.'s analysis of 55 TKAs undergoing DAIR between 2009 and 2017 found an overall treatment success of 60% (23). Kim *et al*.'s retrospective comparison of outcomes between two-stage revision and two-stage revision after failed DAIR reported a total of 228 cases as treated with DAIR. Of these 228, 135 were defined as 'successful', equating to success for 59.2%, for cases identified between 2000 and 2015 (24). Bene *et al*. reported that 72.5% of 76 patients with acute PJI (between 2004 and 2012) treated with DAIR required no further operative intervention for infection, with a mean follow-up of 3.5 years (25). Duffy *et al*. report a treatment success of 69% in their retrospective review of 59 patients undergoing DAIR for PJI, with a median duration of 2.25 years (26). Weston *et al*. reported their experience of DAIR for acute knee PJI paired with long-term suppressive antibiotics. Their retrospective review of 134 infected TKAs between 2000 and 2014 demonstrated infection-free survival of 72% at 2 years, and 66% at 5 years (27). A treatment success of 88.0% was reported by Son *et al*. in a retrospective review of 25 cases between 2010 and 2014 managed with DAIR (28). Chang *et al*. reported their outcomes of a 'modified' DAIR technique for acute knee PJI, in which antibiotic impregnated cement beads are implanted in the medial and lateral gutters and suprapatellar space (and removed at 6 weeks), and compared them to standard two-stage revision. An infection control rate of 78% was demonstrated in both groups (9 knees in each group, treated between 2012 and 2013) (29). Finally, Leta *et al*. analysed 644 TKAs revised for infection as recorded in the Norwegian Arthroplasty Register between 1994 to 2016 to assess success after DAIR, one- and two-stage revision. This demonstrated a survival rate for revision for infection at 5 years as 79% after DAIR (and 87% for both types of formal revision) (30). A further subanalysis undertaken to assess influence of time period on outcome (1994 to 2004 *vs*. 2005 to 2016) did not find any significant differences. It should be noted that a limitation of this study is that treatment failure was defined as revision surgery, so would have excluded other treatments for PJI recurrence, making this estimate of success a likely overestimate.

Functional outcomes following DAIR

There are relatively few studies reporting the functional outcomes after knee DAIR for PJI (*Table 2*). Dzaja *et al*. retrospectively reviewed patient records from 1991 to 2011, and included the 12-Item Short Form Health Survey (SF12), Western Ontario and McMaster Universities Arthritis Index (WOMAC) and Knee Society Scores (KSS). For those cases defined as 'infection eradicated' there were no significant differences in the SF12, WOMAC or KSS compared to outcomes for matched patients with non-infected primary TKA. Patients who failed treatment after DAIR demonstrated no significant difference in functional scores to patients having undergone two-stage revision, who's scores were significantly worse than the matched primary TKA patients (17). Iza *et al*.'s report of 26 knee DAIRs between 2004 and 2016 found at the end of follow-up that patients with treatment failure had a mean KSS of 75, and those with success a score of 65 (non-statistically significant difference) (21). Aboltins *et al*. reported SF12 after DAIR in 37 cases (combination of hip and knees), and found no significant difference at 1 year for both the Physical Component Summary and Mental Component Summary of the SF12 compared to patients after primary joint replacement (31). Barros *et al*. similarly demonstrated no significant difference in patients after DAIR (for hip or knee PJI) as assessed by Hip Disability and Osteoarthritis Outcome Score or Knee Injury and Osteoarthritis Outcome Score, compared to matched patients after primary arthroplasty (32). These recent studies have not demonstrated significant differences in functional outcomes between successful DAIR and primary TKA, which is encouraging. No direct comparisons of functional outcomes after DAIR and staged revision were found. Yahgmour *et al*.'s systematic review of outcomes after single stage revision for TKA PJI did not include a meta-analysis due to outcome heterogeneity. However, functional outcomes were reported in some studies. These included KSS, with average scores of 42–72, and WOMAC, with average scores of 49.5–88 (33). A narrative review by Pangaud *et al*. reported mean KSS after single stage (80; range, 72–88) and two-stage revisions (78; range, 64–86). Range of motion was also reported, with a mean of 91.4° for single stage and 97.8° for two-stage revision (34). In comparison to the figures presented in *Table 2*, these suggest that DAIR is at least equivalent with regards to functional outcomes. However, this is based on comparisons between separate retrospective

Table 2 Functional outcomes after DAIR

Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Outcomes
Iza *et al*., 2019, Spain	Retrospective cohort	2004–2016	Included acute post-operative and acute haematogenous (symptoms <3 weeks)	26 patients	Mean 3.4 (range, 1–12) years	KSS of 75 in DAIR failure group *vs*. 65 in treatment success group (non-significant difference)
Barros *et al*., 2019, Portugal	Retrospective case-control	2010–2016	Acute post-operative infection	(I) DAIR (26 patients); (II) Matched controls (52 patients)	Mean 42.1 (range, 24–66) months	No significant difference in all KOOS domains (pain, activities, sports, quality of life and other symptoms) after successful DAIR and primary TKA
Son *et al*., 2017, Korea	Retrospective cohort	2010–2014	PJI within 4 weeks of primary TKA, or acute haematogenous with ≤5 days symptoms	25 patients	Mean 29.4 (range, 24–35) months	In treatment success cohort, mean Lysholm score of 81.4, mean KKS 79.4, ROM 115.4±12.9°
Dzaja *et al*., 2015, Canada	Retrospective cohort	1991 - 2011	Included acute post-operative and acute haematogenous (symptoms ≤4 weeks)	(I) DAIR (54 patients); (II) 2SR (91 patients); (III) matched primary TKA	Mean 64.2 (range, 12–237) months for PJI group; mean 35.4 (range, 24–120) months for control group	Successful DAIR *vs*. primary TKA: no significant differences in mean SF12, KSS (150.1 *vs*. 160.8), WOMAC (72.1 *vs*. 75.6) or ROM (110.9 *vs*. 109); 2-stage revision *vs*. primary TKA: significantly lower scores for 2SR cohort; Failed DAIR *vs*. 2SR: No significant differences
Aboltins *et al*., 2015, Australia	Retrospective cohort	2006–2009	Included acute post-operative (<3 months after implantation) and acute haematogenous	41 patients (mix of hip and knee arthroplasty)	Mean 688 days	No statistically significant difference in change between pre-operative and 12-month score of SF12 physical component summary and mental component summary in DAIR and primary arthroplasty

TKA, total knee arthroplasty; PJI, periprosthetic joint infection; DAIR, debridement, antibiotics and implant retention; 2SR, 2-stage revision; SF12, medical outcomes study short form; WOMAC, Western Ontario and McMaster Universities Arthritis Index; KOOS, Knee Injury and Osteoarthritis Outcome Score; KSCS, knee society clinical score; KSFS, knee society functional score; ROM, range of motion; KKS, Korean Knee Score.

studies. In the management of hip PJI, there is evidence of superior functional outcomes (as assessed by the Oxford Hip Score) in patients treated successfully with DAIR *vs.* two-stage revision (16). Direct comparisons are needed in the management of knee PJI to determine differences in functional outcome between successful DAIR, one stage revision and two-stage revision.

Mortality following DAIR

Given the typically small retrospective cohort studies used to report outcomes after knee DAIR, a clear understanding of the influence of DAIR on mortality is difficult. Leta *et al.*'s analysis of the Norwegian register included 90-day and 1-year mortality rates after surgical treatments for knee PJI, however the register does not record cause of death. Approximately half (329 of 644) of the cohort analysed underwent DAIR, with a 90-day and 1-year mortality rate of 2.1% and 3.6% respectively (*Table 3*). One-stage revisions (72 cases) had a mortality of 0%, and for two-stage revision (243 cases) mortality rate of 1.2% and 2.5% (30). Weston *et al.*'s analysis of DAIR coupled with chronic antibiotic suppression included mortality rates. They report that DAIR for acute post-operative infection had a 5-year survival of 81% *vs.* 68% in the acute haematogenous group (27). There was no significant difference in 2-year mortality secondary to PJI in Kim *et al.*'s analysis of two-stage revision after failed DAIR *vs.* two-stage revision (1.3% *vs.* 1.6%) (24). Urish *et al.* reported a significant 5 year mortality of 19.9%, similar to reports by Choi and Zmistowski for PJI cases (18% at 4 years and 26% at 5 years respectively) (10,35).

DAIR in unicompartmental knee arthroplasty (UKA)

In comparison to DAIR for TKA there is a scarcity of evidence published specifically regards DAIR for UKA. This may be explained in part due to lower numbers of UKAs implanted (~8% of knee replacements performed annually in the UK), and the lower revision for infection risk seen in primary UKA of (hazard ratio of 0.5 (95% CI: 0.38–0.66) compared to primary TKA) (36,37). A retrospective review of 15 UKA PJIs between 1992 and 2014 found a higher treatment success for two-stage revision (100% at 5 years) than for DAIR (61% at 5 years) (38). Retained cartilage in native compartments following UKA may present an additional mode of failure after DAIR, beyond infection recurrence. Chondrolysis after initial PJI, with progressive arthritis of native compartments, may necessitate additional surgery for symptom control (39). The ICM recommendation, in light of a lack of evidence, is that early DAIR can be considered, with one or two-stage revision (with conversion to TKA) used for treatment failure or in the setting of established infection (40).

Factors affecting outcome

Chronicity of DAIR

There are several variables recognised to influence the success of DAIR for infection control of PJI, with chronicity of infection one such factor. Specifically, the more chronic the duration of PJI, the less successful is DAIR. Kunutsor *et al.*'s meta-analysis reported infection control of 67.7% (95% CI: 68.9–81.5%) for acute postoperative infection, and 52.7% (95% CI: 40.8–64.5%) for acute haematogenous infection, falling to 31.9% (95% CI: 8.5–60.2%) in late chronic PJI (*Table 4*) (18). A similar pattern was demonstrated in subgroup analyses exploring time from primary implantation to symptom onset, duration of symptoms before DAIR and time from index primary implantation to DAIR (shorter windows demonstrated better success). It should be noted that these figures include DAIR outcomes of different joints, with the same meta-analysis demonstrating lower success rates for knee DAIR compared to hip, shoulder and elbow. However, Ottesen *et al.* reported that DAIR within 90 days of primary implantation had treatment success of 90% *vs.* 60% for those revised with DAIR beyond 90 days (41). Narayan *et al.* similarly found that patients undergoing DAIR sooner after index TKA (≤2 *vs.* >2 weeks) had greater treatment success (23). Qu *et al.* demonstrated that a symptom period of >3 weeks resulted in reduced DAIR success rates for knee PJI (20). The lower success for infection eradication associated with the duration of infection is likely related to the development of a mature biofilm on prosthetic surfaces. Both the mature biofilm, and the metabolic changes of bacteria within in the biofilm, demonstrate resistance mechanisms to host defences and antibiotics. Classically these time windows have been described as acute post-operative (≤3–6 weeks after primary implantation), acute haematogenous (any time after the acute post-operative period and with a short symptom history) or chronic. Acute post-operative PJI is likely secondary to operative contamination, whereas acute

Table 3 Mortality after DAIR

Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Mortality	Other comments
Leta *et al*., 2019, Norway	Registry cohort	1994–2016	Not stated	(I) DAIR (n=329); (II) 1SR (n=72); (III) 2SR (n=243)	Mean 5.1 (range, 0.01–21.9) years	Within 90 days: 2.1% for DAIR, 0% for 1SR and 0.4% for 2SR; within 1 year: 3.6% for DAIR, 0% for 1SR, 1.6% for 2SR	Study data did not include cause of death, so could not determine if these rates due to PJI, surgery or other reasons
Kim *et al*., 2019, New Zealand	Retrospective cohort	2000–2015	Not stated, but included 'all patients with first episode of PJI'	(I) 2SR (n=63); (II) 2SR after failed DAIR (n=75)	Mean 5.8±3.7 years in 2SR group; mean 6.5±3.7 years after DAIR & 2SR	2-year mortality due to PJI: 2SR group: 1.6%; DAIR & 2SR: 1.3%. 2-year mortality due to 'other' reasons: 2SR: 14.3%; DAIR & 2SR: 4.0%	Statistically significant increase in mortality after 2SR for 'other' reasons, but causes not detailed in report. Higher mean ASA and CCI in 2SR group
Weston *et al*., 2018, United States	Retrospective cohort	2000–2014	Acute post-operative (≤4 weeks after primary TKA) and acute haematogenous (>4 weeks after primary TKA and <3 weeks of symptoms)	134 knees	Mean 5.0 (range, 2.1–13) years	KM survival analyses performed: 90 days: 95% (95% CI: 91–99%), 1 year: 91% (95% CI: 86–98%), 2 years: 85% (95% CI: 78–100%), 5 years: 72% (95% CI: 64–82%)	All patients received long-term oral suppressive antibiotics after DAIR in this treatment protocol; KM survival subgroup analysis (post-operative and acute haematogenous PJI) also reported
Urish *et al*., 2018, United States	Retrospective cohort	2005–2015	Not stated. Cases identified using ICD-9 codes and MSIS criteria	216 knees	Median 13.5 (IQR 14.4–67.0) months	1-year mortality: 7.8%; 2-year mortality: 10.7%; 5-year mortality: 19.9%	Cohort included failed DAIR who went onto repeat DAIR, 1SR, 2SR, amputation or fusion
Choi *et al*., 2014, United States	Retrospective cohort	2000–2010	Chronic PJI matched to non-PJI revision TKA	(I) 2SR for PJI (88 patients); (II) revision TKA not for PJI (88 patients)	Median 4 (IQR 2–7) years	Mortality in PJI group: 18%; mortality in non-PJI group: 3%	Statistically significant increasing in mortality after 2SR for PJI *vs*. revision not for PJI. This was not a comparison of DAIR treatment
Zmistowski *et al*., 2013	Retrospective cohort	2000–2010	Not specified. PJI diagnosed using modified MSIS criteria.	436 patients	Not detailed Maximum 5 years	90-day survival: 96.3%; 1-year survival: 89.5%; 2-year survival: 86.5%; 5-year survival: 73.9%	Mixed cohort of hip and knee arthroplasty patients undergoing revision arthroplasty for PJI

1SR, 1-stage revision; 2SR, 2-stage revision; TKA, total knee arthroplasty; PJI, periprosthetic joint infection; KM, Kaplan Meier; CI, confidence interval; ICD-9, international classification of diseases, 9th edition; MSIS, musculoskeletal infection society.

Table 4 Chronicity of PJI and DAIR

Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Outcomes	Other comments
Qu *et al.*, 2019, China	Meta-analysis	Studies Prior to Jan 2018	Mixed	Symptom duration <3 weeks (n=357); symptom duration >3 weeks (n=57)	Mixed	Infection control in <3-week group 71.15% (95% CI: 66–76%); infection control in >3-week group 35.09% (95% CI: 23–47%)	Statistically higher treatment success with early DAIR
Kunutsor *et al.*, 2018, UK	Meta-analysis	Studies prior to May 2017	Mixed	Acute post-operative (n=1,037); acute haematogenous (n=234); late chronic (n=119); <21 days symptoms (n=1,832); ≥21 days symptoms (n=393)	Mixed	Infection control rates provided as % with 95% CI: acute post-operative: 67.70% (95% CI: 59.60–75.50%); acute haematogenous: 52.70% (95% CI: 40.80–64.50%); late chronic: 31.90% (95% CI: 8.50–60.20%); <21 days symptoms: 65.10% (95% CI: 59.60–70.50%); ≥21 days symptoms: 42.80% (95% CI: 20.70–66.40%)	Infection control rate by PJI type was statistically significant (note: analysis includes DAIRs of various joints)
Ottensen *et al.*, 2018, Denmark	Retrospective cohort	2008 to 2013	All PJI after primary TKA treated with DAIR	DAIR within 28 days (n=34); DAIR after 90 days (n=10)	Minimum 2 years	Success if DAIR within 28 days: 85%; success if DAIR after 90 days: 60%	Cases categorised based on timing of DAIR after surgery, rather than duration of symptoms
Narayan *et al.*, 2018, United States	Retrospective cohort	2009 to 2017	Mixed	DAIR ≤2 weeks after index TKA (n=17); DAIR >2 weeks after index TKA (n=38)	Mean 2.5 years	Early DAIR: treatment success 82%; Late DAIR: treatment success 50%	Statistically greater treatment success when DAIR performed within 2 weeks of index TKA

TKA, total knee arthroplasty; PJI, periprosthetic joint infection; DAIR, debridement, antibiotics and implant retention; CI, confidence interval.

haematogenous results from seeding of bacteria from other sites. Whilst useful as a clinical guide, there are recent suggestions to move away from such a classification, given greater understanding of biofilm formation (42).

Causative organism and DAIR outcome

The causative organism is also an important factor influencing the likely success of DAIR. Broadly, those organisms with broader antimicrobial resistance profiles will be more difficult to eradicate, as are those able to rapidly produce biofilms or with multiple defences against host immune responses. The majority of PJI are caused by Gram-positive cocci, in particular *Staphylococcus aureus*, and coagulase negative *Staphylococci* (CoNS). Polymicrobial infection is also found in a significant proportion of knee PJI. Other common organisms include *Streptococci*, *Enterococci*, aerobic Gram-negative bacilli and anaerobic bacteria. Within the literature a wide range of other bacterial species have been identified as causative organisms in PJI. Kunutor *et al*. have demonstrated the influence of organism on DAIR success, with *Staph. aureus* associated with a slightly lower success of infection eradication (56.5%, 95% CI: 41.7–70.7), compared to other Gram-positive and Gram-negative organisms (*Table 5*) (18). Iza *et al*. recently reported a similar finding, with *Staph. aureus* being associated with poorer treatment success *vs*. non-*Staph. aureus* species (21). Fungal PJI is thankfully rare, and is mainly seen in hosts who are otherwise immunocompromised. DAIR is not appropriate in these settings, and two-stage revision should be considered. Finally, 'culture negative' PJI represents the scenario with a clinically infected prosthesis, but where no organisms are identified on culture. This can be a result of failure to sample, difficult to culture organisms or administration of antibiotics prior to sampling (43,44). New molecular tools for culture-negative PJI diagnosis are being actively investigated (45).

Host factors and DAIR outcome

Host factors are believed to influence the likelihood of success after DAIR. The McPherson staging system considers systemic features (such as immunocompromise, advanced age and malnutrition) and local limb features (such as poor soft tissue envelope and vascular insufficiency) in an effort to identify patients who are at risk of a poor outcome. Bryan *et al*. demonstrated that healthy patients (McPherson Grade A) had a lower treatment failure rate than unhealthy patients (McPherson Grade C), at 8% *vs*. 44% over a median follow-up of 6 years, for DAIR in the setting of acute hip PJI (46).

Technical aspects of DAIR and outcome

The technical aspects of DAIR surgical technique have been described elsewhere in this issue, but there is evidence that the method of DAIR has an influence on treatment success. Byren *et al*. found a significantly higher risk of treatment failure in a retrospective cohort of 112 mixed joint DAIRs, with a hazard ratio of 4.2 (95% CI: 1.5–12.5) for arthroscopic *vs*. open DAIR (47). The recent International Consensus Meeting found a strong majority and consensus against the role of arthroscopy in management of PJI (40).

Where possible it is recommended that modular components are exchanged, with evidence supporting improved treatment success where this is done (40). This intuitively makes sense as removal of a modular polyethylene bearing not only results in the reduction of the bioburden, but it also allows access to the posterior capsule of the knee joint for debridement. From a general DAIR perspective Lora-Tamayo *et al*. demonstrated higher treatment failure of DAIR when component exchange was not performed in a multi-centre review of 349 hip and knee PJIs (48). Choi *et al*. reported a significant benefit of polyethylene exchange in knee DAIR, with a 52.6% success rate *vs*. 0% without exchange (49).

Closing statements

DAIR is a viable option in managing acute PJI following knee arthroplasty and there is growing interest in identifying cases amenable to DAIR with a high chance of treatment success. The advantage of this technique in comparison to formal staged revision surgery is the reduced morbidity and better functional outcomes. The evidence base largely consists of small cohort studies (often retrospective), rather than randomised controlled trials. Meta-analyses have been undertaken to improve outcome estimates, but heterogeneity in diagnostic criteria, causative organisms, surgical technique, antibiotic regimens and definitions of treatment/failure success are limitations. The key points in achieving a positive outcome after DAIR for PJI are largely agreed to be a short clinical duration of infection, exchange of modular components (where

Table 5 Organisms in DAIR

Report details	Study type	Study time period	PJI type	Study groups	Follow-up period	Outcomes	Other comments
Kunutsor *et al*., 2018, United Kingdom	Meta-analysis	Studies prior to May 2017	Mixed	Gram negative (n=304); Gram positive (n=461); MRSA (n=62); Staph. aureus (n=443)	Mixed	Infection control rates provided as % with 95% CI: Gram negative: 65.80% (95% CI: 51.60–78.90%); Gram positive: 62.00% (95% CI: 48.80–74.30%); MRSA: 60.20% (95% CI: 47.50–72.30%); *Staph. aureus*: 56.50% (95% CI: 41.70–70.70%)	Streptococcal infection control reported as greater (89.5%) than staphylococcal (75.2%) (note, analysis includes DAIRs of various joints)
Iza *et al*., 2019, Spain	Retrospective cohort	2004–2016	Post-operative & acute haematogenous PJI with symptoms <3 weeks	26 patients included	Mean 3.3 (range, 1–12) years	Statistically significantly lower treatment success in *Staph. aureus* infections (33%) *vs.* non-*Staph. aureus* infections (83%)	*Staph. aureus* group n=3 *vs.* n=23 (6 gram negative bacilli, 5 CoNS *Staphylocci*, 3 *Streptococci*, 1 polymicrobial, 1 'anaerobe' and 7 culture negative cases)
Ottensen *et al*., 2018, Denmark	Retrospective cohort	2008–2013	All PJI after primary TKA treated with DAIR	DAIR within 28 days (n=34); DAIR after 90 days (n=10)	Minimum 2 years	Treatment success of 89% *Staph. aureus* infections (89%), 87% in CoNS infections and 75% in *Streptococcus* infection	Infections not presented by duration of PJI, and some cases had sinuses indicating chronic infection
Bene *et al*., 2018, United States	Retrospective cohort	2004–2012	Acute PJI (<4 weeks of symptoms after primary TKA)	76 patients	Mean 3.5 (range, 0.1–9.7) years	Standardised difference score given for each organism type: MRSA: 0.7479; MSSA: 0.3067; non-*S.aureus* staphylococcal species: 0.148; non-*Staph* Gram positive: –0.0500; culture negative: –0.3977; Gram negative: –0.4248	Higher score indicates higher incidence of reoperation for infection, negative score a lower incidence

TKA, total knee arthroplasty; PJI, periprosthetic joint infection; DAIR, debridement, antibiotics and implant retention; UK, United Kingdom; MRSA, methicillin resistant *Staphylococcus Aureus*; CI, confidence interval; CoNS, coagulase-negative *Staphyloccal species*; MSSA, methicillin sensitive *Staphylococcus aureus*.

possible), an organism with antibiotic sensitivities, and an uncompromised host. Publications over the last 20 years reporting the outcome of DAIR for acute PJI typically report treatment success rates of ~50–70%, within the limitations detailed above. Functional outcomes appear generally good compared to formal revision surgery, but few studies report these. Improving consensus regarding diagnosis, organisms, treatment and outcome definitions will allow greater comparisons in future work, and more robust pooling of data across centres for meta-analysis.

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