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Original research

Cost-effectiveness of Single vs Double Debridement and Implant Retention for Acute Periprosthetic Joint Infections in Total Knee Arthroplasty: A Markov Model

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A B S T R A C T

Background: Periprosthetic joint infection (PJI) is a common cause of revision total knee surgery. Although debridement and implant retention (DAIR) has lower success rates in the chronic setting, it is an accepted treatment of acute PJI, whether postoperatively or with late hematogenous seeding. There are two broad DAIR strategies: single debridement and planned double debridement. The purpose of this study is to evaluate the cost-effectiveness of single vs double DAIR for acute PJI in total knee arthroplasty.
Methods: A decision tree using single or double DAIR as the treatment strategy for acute PJI was constructed. Quality-adjusted life years and costs associated with the two treatment arms were calculated. Treatment success rates, failure rates, and mortality rates were derived from the literature. Medical costs were derived from both the literature and Medicare data. A cost-effectiveness plane was constructed from multiple Monte Carlo trials. A sensitivity analysis identified parameters most influencing the optimal strategy decision.
Results: Double DAIR was the optimal treatment strategy both in terms of the health utility state (82% of trials) and medical cost (97% of trials). Strategy tables demonstrated that as long as the success rate of double debridement is 10% or greater than the success rate of a single debridement, the two-stage protocol is cost-effective.
Conclusions: A double DAIR protocol is more cost-effective than single DAIR from a societal perspective.

Introduction

Periprosthetic joint infection (PJI) is the most common cause of revision surgery for total hip and total knee arthroplasty (TKA) [1,2], accounting for an estimated $1.6 billion in cost to the health-care system, and is projected to grow to approximately $1.8 billion annual hospital cost by 2030 [3,4]. PJI is associated with patient morbidity and inferior patient outcomes even when treated successfully [5].

The management of PJI differs depending on whether the infection is acute or chronic. While the gold standard remains 1-stage or 2-stage exchange revision for the treatment of chronic PJI, debridement and implant retention (DAIR) still plays an important role in the management of acute postoperative or late hematogenous PJI. An international workgroup on the diagnosis and treatment of PJI recently recommended that DAIR should be reserved for acute cases of infection, defined as symptoms existing for no longer than 4 weeks with a stable implant [6].

There are two primary strategies for treating acute PJI with DAIR: single and planned two-stage (double) debridement. In the two-stage debridement, the first stage consists of extensive debridement, disassembly and sterilization of all modular parts, and the delivery of high-dose local antibiotics typically through the use of nonabsorbable beads. The second stage, typically occurring 5-7 days later, consists of a second thorough debridement, removal of the antibiotic beads, and exchange of modular parts [7].

The purported advantages of a two-stage approach include the ability to deliver high-dose local antibiotics between stages, the presence of a more "sterile" field at the second-stage procedure, repeat debridement, and higher success rates than single

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debridement [7-32]. Concerns about this approach include higher initial costs, longer hospital stays, and potential morbidity associated with a second procedure. The purpose of this study is to evaluate the cost-effectiveness of single vs double DAIR for acute PJI in TKA. We hypothesized that a double DAIR technique would be cost-effective compared to a single debridement.

Material and methods

The base case is a 65-year-old patient with a history of TKA 5 years ago, who presents with 5 days of acute onset knee pain. The patient has an elevated C-reactive protein (>100 mg/dL), and aspiration reveals 2 positive cultures, meeting the International Consensus Meeting criteria for acute PJI [33]. The patient's total knee replacement was well functioning before the recent onset of symptoms, implants were radiographically stable, and the duration of symptoms was clear.

Decision model

Our model is an adaptation of the model published by Srivastava et al. [34], which evaluated the cost-effectiveness of 1-stage vs 2-stage revision for chronic PJI in TKA. Decision trees were constructed for acute PJI (Fig. 1). Patients entered into the single DAIR or double DAIR treatment strategy. In the single DAIR arm, patients can transition to three different states: success, failure, or death. In the double DAIR arm, a small percentage of patients may fail to proceed to the second debridement. After the double debridement, patients transition into the same states as for the single debridement: success, failure, or death. Treatment failure or residual infection after DAIR resulted in death, chronically retained infection, or treatment with 2-stage revision. The probability of each event was a mean value obtained from a literature review of articles published over the past 20 years using the PubMed database. Keyword searches used were "periprosthetic joint infection", "DAIR", "debridement", "implant retention", "acute", "irrigation

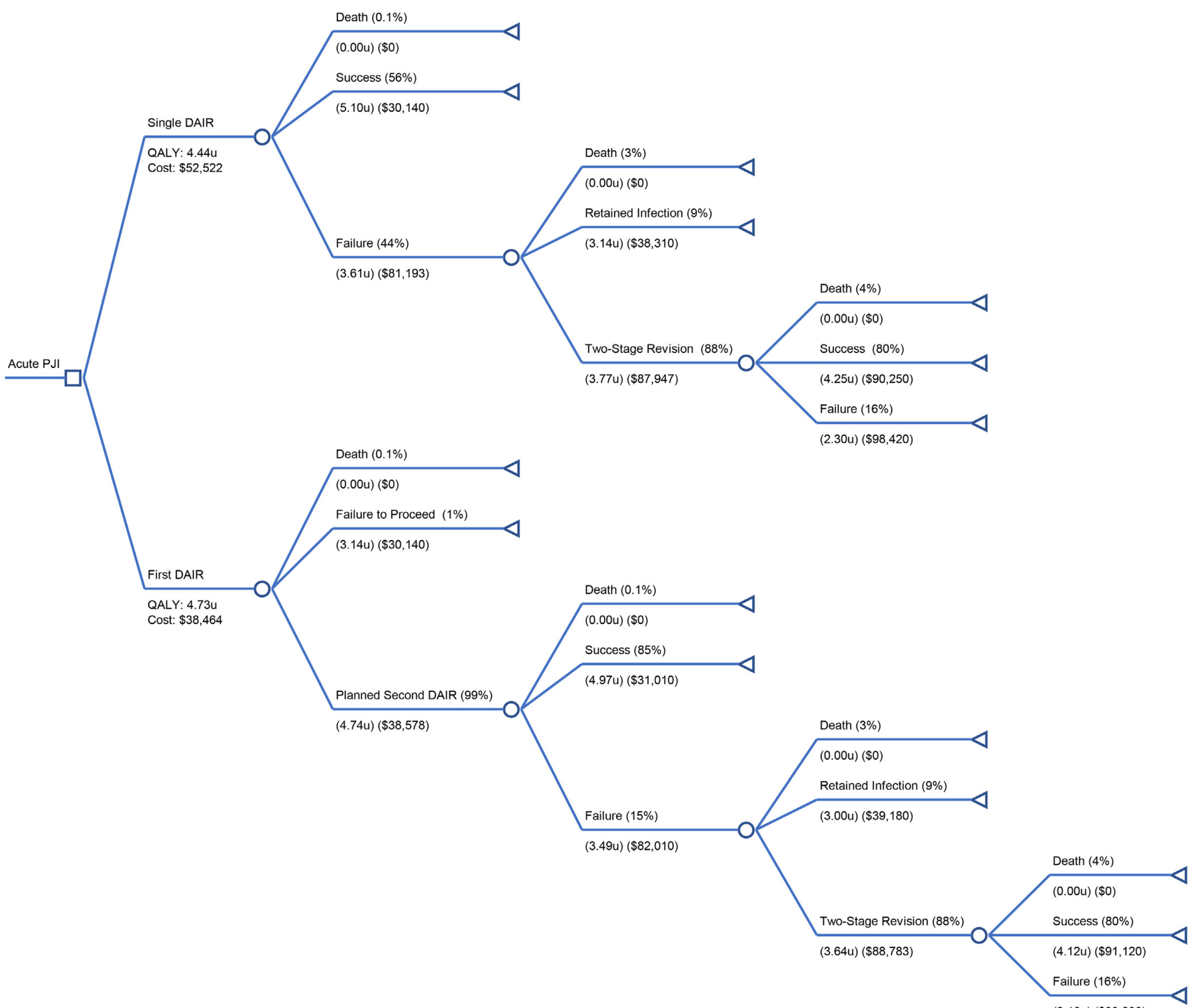

Figure 1. Decision tree (with rollback analysis QALYs and costs).

and debridement", "multiple debridement", "repeat debridement", "two-stage debridement", and "hematogenous". Articles including only chronic PJI cases were excluded. For studies that reported success rates for chronic PJI, acute postoperative PJI, and late hematogenous PJI, the acute postoperative and late hematogenous PJI success rates were combined and included in this study. Studies where two planned debridements were performed, with the use of a local antibiotic delivery system between the two debridements, were classified as double DAIR studies. Studies where multiple debridements were performed only because of failure of the first debridement were excluded (Table 1, Appendix A).

Quality-adjusted life years

Quality-adjusted life years (QALYs) were used to approximate the quality of life by patients in each treatment group. These were determined based on previously published literature by Srivastava et al. [34] and estimates from the Center for the Evaluation of Value and Risk in Health [52,53]. Well-functioning TKA received a health utility of 0.8, and failure of treatment scored 0.5. Disutility tolls were subtracted from the health utility value whenever a procedure was performed. Two-stage revision received a disutility score of 0.13, and single DAIR scored 0.02 [34,54]. No previous literature exists to estimate the disutility score of a double DAIR; however, given that the protocol involves two planned debridements, the disutility score was assumed to be 0.04 (two times the disutility toll of a single debridement).

QALYs were discounted at an annual rate of 3% [34,55-57]. QALYs were calculated over a 15-year period using a Markov model (Fig. 2). Probability of death per year was obtained from an actuarial life table from the Social Security Administration [58].

Costs

Cost for each procedure was calculated using Diagnosis-Related Group (DRG) 486 and Current Procedural Terminology (CPT) code 27310. The average Medicare reimbursement for CPT 27310 was obtained from the U.S. Centers for Medicare & Medicaid Services website Physician Fee Schedule lookup tool (Table 2) [59,60]. Cost of single DAIR and 2-stage revision were adopted as per the method used by Srivastava et al., with a conversion factor of 1.13 applied to hospital reimbursements [34,61]. There are a wide variety of CPT codes that could potentially apply to cases of single or double debridement. These codes include but are certainly not limited to 27310 (arthrotomy with exploration, drainage, or removal of foreign body [eg, infection]), 27,486 (revision of one component), and 27488 (removal of prosthesis, TKA). Based on codes used in previous literature [34], the cost of double DAIR was calculated as the cost of single DAIR plus that of CPT 27310 given the second procedure is performed under the same DRG. The cost of 6 weeks of intravenous antibiotics after DAIR, or lifelong antibiotic suppression in patients with failure to clear infection and retention of infected components, was also included [34,61].

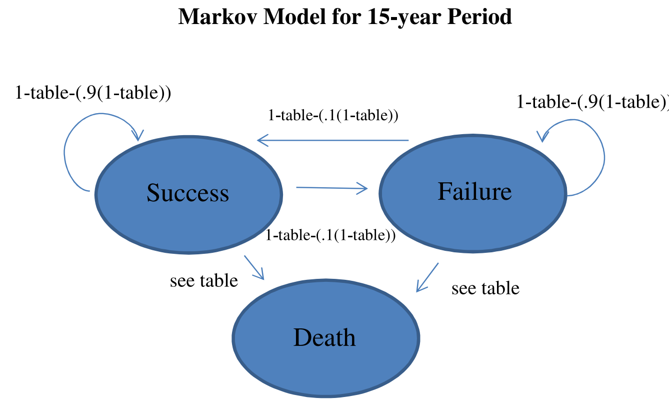

Figure 2. Markov model with the different possible terminal health states, used to calculate 15-year QALYs. "Table" refers to an actuarial table from the Social Security Administration [58].

Analysis

A decision-analysis software program (Frontline Solver; Frontline Systems, Incline Village, NV, USA) was used to determine the optimal decision of single vs double debridement with regard to 15-year QALY and cost. A Monte-Carlo simulation of 1000 trials was performed to determine the dominance of the optimal strategy. A sensitivity analysis was performed with all percentages along the decision tree varied 15% up or down with a uniform distribution

Table 1
Decision model input data including probability of events after single or double DAIR, based on literature review.

Event	Probability	References
After single DAIR		
Success	56%	[12-32]
Failure/reinfection	44%	[12-32]
Death	0.1%	Assumption
Retains infected implant	9%	[7,17,22,23,30]
2-Stage revision after failure	88%	[7,17,22,23,30]
Success of 2-stage revision after failure	80%	[34-48]
Failure after 2-stage revision	16%	[34-48]
Death after 2-stage revision	4%	[35,49-51]
After double DAIR		
Success	85%	[7-11]
Failure to complete two-stage protocol	0.1%	Assumption
Failure/reinfection	15%	[7-11]
Death	0.1%	Assumption
Retains infected implant	9%	[7,17,22,23,30]
2-Stage revision after failure	88%	[7,17,22,23,30]
Success of 2-stage revision after failure	80%	[34-48]
Failure after 2-stage revision	16%	[34-48]
Death after 2-stage revision	4%	[35,49-51]

DAIR, debridement and implant retention.

Table 2
Health state utilities, disutility tolls after different surgical procedures, and medical costs of procedures and associated antibiotic regimens.

Health state	Utility	References
TKA	0.8	[34,52,53]
Treatment failure	0.5	[34,52,53]
Death	0	
Disutility tolls		
Single DAIR	0.02	[34,54]
Double DAIR	0.04	Assumption
Two-stage revision	0.13	[34,54]
Medical costs		
CPT 27310	$870.10	[34,59,60]
DRG 486	$16.853.95	[34,59,60]
Single DAIR	$17,724.05	[34,59,60]
Double DAIR	$18,594.15	[59,60]
Two-stage revision	$47,694.00	[34]
6-wk IV antibiotics	$12,416.00	[34,61]
15-y Oral antibiotics	$8170.00	[34,61]

CPT, Current Procedural Terminology; DAIR, debridement and implant retention; DRG, Diagnosis-Related Group; IV, intravenous; TKA total knee arthroplasty.

Strategy tables were created from the rollback analyses. A cost-effectiveness plane was constructed using both a willingness-to-pay threshold of $50,000 and $100,000 per QALY [34,62].

Results

Using this decision model, double debridement with implant retention was superior to single debridement with implant retention, both in terms of health state utility and cost. Double debridement was the optimal strategy in the Monte Carlo simulation in approximately 82% of the trials with regard to QALYs gained (Fig. 3). It was also the optimal strategy in terms of cost in approximately 97% of trials. Average expected QALYs by rollback analysis using the double debridement strategy were 4.73 as compared to 4.44 for single debridement. The double debridement strategy resulted in a lower cost than the single debridement strategy using rollback analysis; the average rollback cost of double debridement was $38,464 vs $52,522 for single debridement (Table 3).

Table 3
Table of the net utility difference and net cost difference between single and double DAIR as determined by the rollback analysis.

	Single DAIR	Double DAIR
QALYs	4.44	4.73
Health-care costs	$52,522	$38,464

DAIR, debridement and implant retention; QALY, quality-adjusted life years.

Results of the rollback analysis with 15-year discounted QALY and total cost are shown in Figure 1. Results of the rollback analysis using a uniform distribution for the likelihood of success for single debridement (success rate ranging between 30% and 70%) and double debridement (success rate ranging between 60% and 95%) are shown in Figure 4.

Strategy tables

Although the rates of success for single and double debridement were based on a literature review, many factors including host

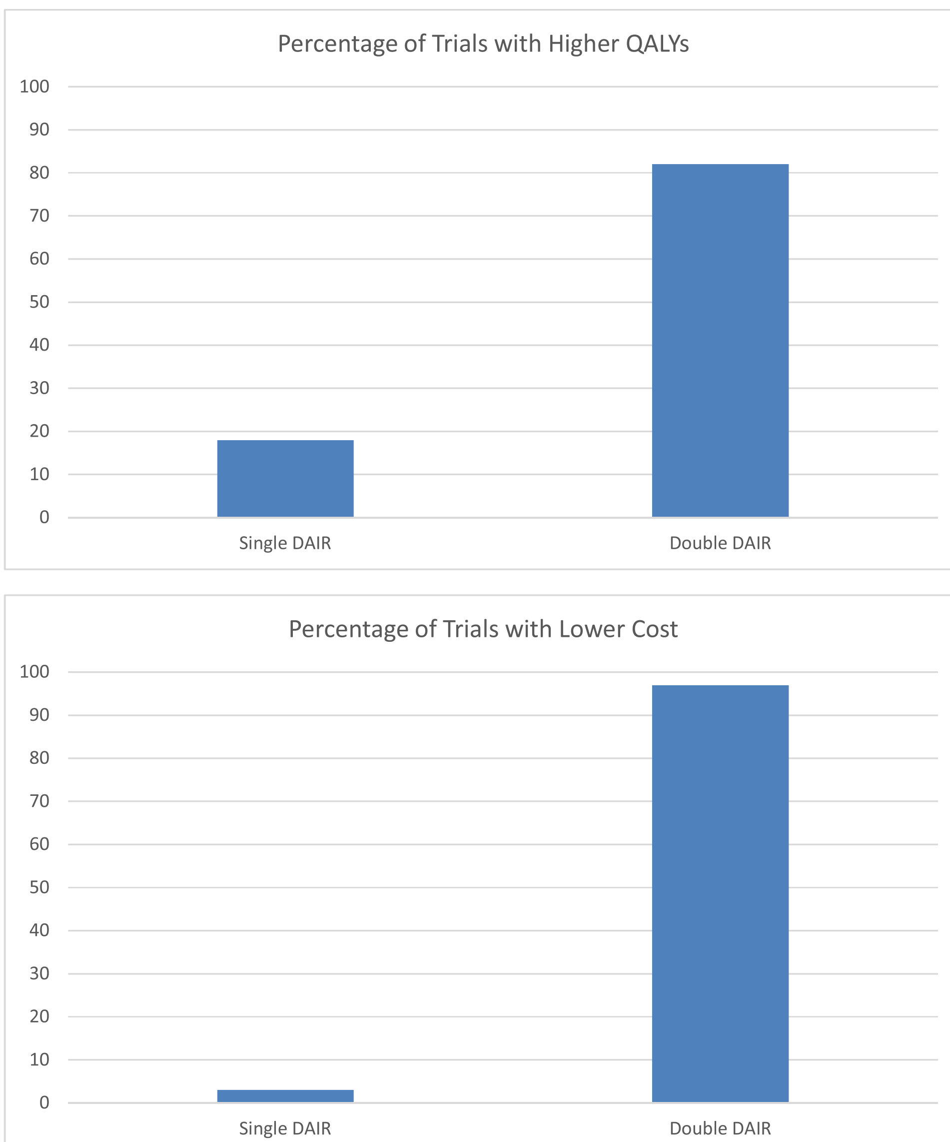

Figure 3. Results of the decision model. Double debridement was the optimal strategy in the Monte Carlo simulation in approximately 82% of the trials with regard to QALYs gained and in approximately 97% of trials with regard to cost.

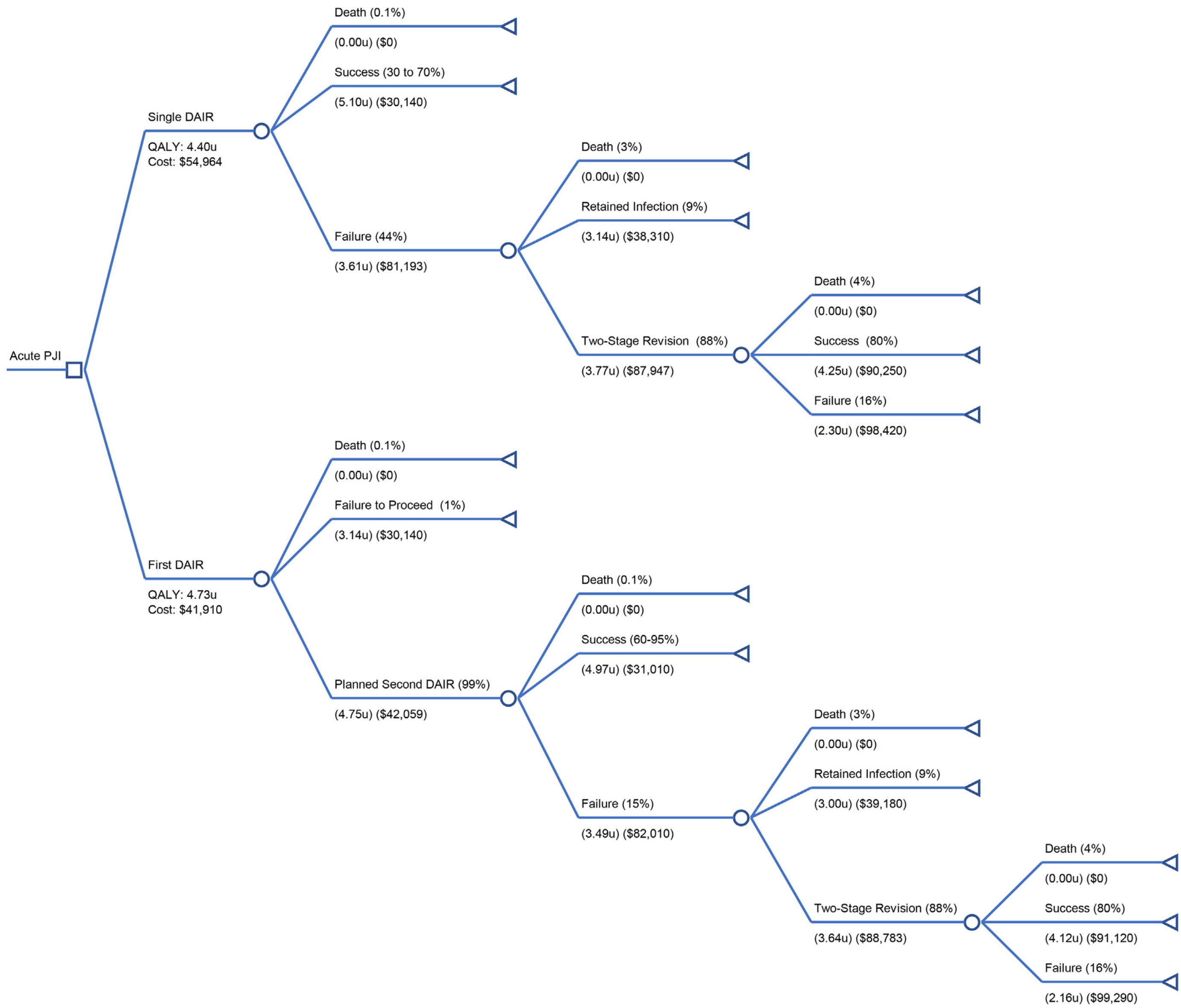

Figure 4. Rollback analysis using a uniform distribution for the likelihood of success for single DAIR (success rate ranging between 30% and 70%) and double DAIR (success rate ranging between 60% and 95%). Associated 15-year QALYs and costs are shown.

biology and pathogen type do play a significant role in treatment success or failure [10,29,32]. Strategy tables were created from the rollback analysis, varying the success rates of each debridement strategy. As seen in Figure 5, double debridement is the preferred treatment choice with regard to health utility, cost, and cost per QALY as long as the success rate is approximately 10% greater than that of a single debridement.

Sensitivity analysis

Results of the sensitivity analysis are demonstrated by the Tornado Chart in Figure 6. Each parameter along the decision tree was varied by 15% (increase or decrease) in a uniform distribution. The most sensitive variable was the success rate of two-stage revision after failed single debridement, followed by the percentage of patients who go on to two-stage revision after a failed single-stage debridement. As both of these values increase, the relative benefit of the double debridement protocol with regard to QALYs gained decreases.

Incremental cost-effectiveness

A cost-effectiveness plane was generated to demonstrate the incremental gains in QALYs and incremental cost savings with planned double debridement (Fig. 7). The vast majority of trials are to the right of willingness-to-pay thresholds of $50,000 and $100,000 per QALY, designating cost-effectiveness. In most trials, double debridement led to not only improved health utility but also cost saving.

Discussion

DAIR has many advantages over component revision which makes this treatment an attractive option in the setting of acute PJI.

a

Probability of Double DAIR Success \ Probability of Single DAIR Success	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.3	1	1	1	1	1	1	1
0.4	2	1	1	1	1	1	1
0.5	2	2	1	1	1	1	1
0.6	2	2	2	1	1	1	1
0.7	2	2	2	2	1	1	1
0.8	2	2	2	2	2	1	1
0.9	2	2	2	2	2	1	1

b

Probability of Double DAIR Success \ Probability of Single DAIR Success	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.3	1	1	1	1	1	1	1
0.4	2	1	1	1	1	1	1
0.5	2	2	1	1	1	1	1
0.6	2	2	2	1	1	1	1
0.7	2	2	2	2	1	1	1
0.8	2	2	2	2	2	1	1
0.9	2	2	2	2	2	2	1

c

Probability of Double DAIR Success \ Probability of Single DAIR Success	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.3	1	1	1	1	1	1	1
0.4	2	1	1	1	1	1	1
0.5	2	2	1	1	1	1	1
0.6	2	2	2	1	1	1	1
0.7	2	2	2	2	1	1	1
0.8	2	2	2	2	2	1	1
0.9	2	2	2	2	2	2	1

Figure 5. Strategy tables created from the rollback analysis demonstrating the optimal strategy as the probabilities of the success of single and double DAIR vary in terms of (a) QALY, (b) cost, and (c) cost per QALY. When single DAIR is the optimal strategy, this is represented with the value “1”. When double DAIR is the optimal strategy, this is represented with the value “2”.

Most notable advantages include lower morbidity and lower surgical complexity. Results of DAIR for the management of chronic PJI have been poor, leaving 1-stage or 2-stage exchange revision as the treatments of choice [63-65]. However, in acute postoperative or acute hematogenous infection, DAIR remains a viable management strategy. While the success rate of DAIR in acute PJI has been shown to improve with a double debridement approach, the double DAIR is not currently considered standard of care [7-11]. Many surgeons may be hesitant to adopt this approach because of concerns regarding increased length of hospital stay, cost, and the added morbidity of a second procedure. However, if shown to be cost-effective, the double DAIR strategy may warrant further consideration as a treatment strategy for acute PJI. The purpose of this study was to examine the cost-effectiveness of single vs double DAIR in the management of acute PJI in TKA.

In this decision model analysis, double debridement was found to be more cost-effective than single debridement. Double debridement afforded a better health utility state and lower costs in the vast majority of simulations. Previous studies have demonstrated a higher success rate of double debridement vs single-stage DAIR, with a difference in mean success rates reported in the available literature between the two techniques nearing 30% (Appendix A; [7-32]). The created strategy tables in this analysis show that double debridement would continue to be cost-effective even if the difference in success rates was smaller; as low as about 10%.

The model used in this study is adapted from that used by Srivastava et al. in a study comparing the cost-effectiveness of 1-stage or 2-stage revision for the management of chronic PJI in TKA [34]. In that study, 1-stage revision produced the highest QALY. Given the results of their literature review demonstrating nearly equal success rates with 1-stage and 2-stage revision and the decreased morbidity of a 1-stage revision as compared to a 2-stage revision, this outcome may be expected. However, in the setting of acute PJI, the literature shows that the success rates of treating infection

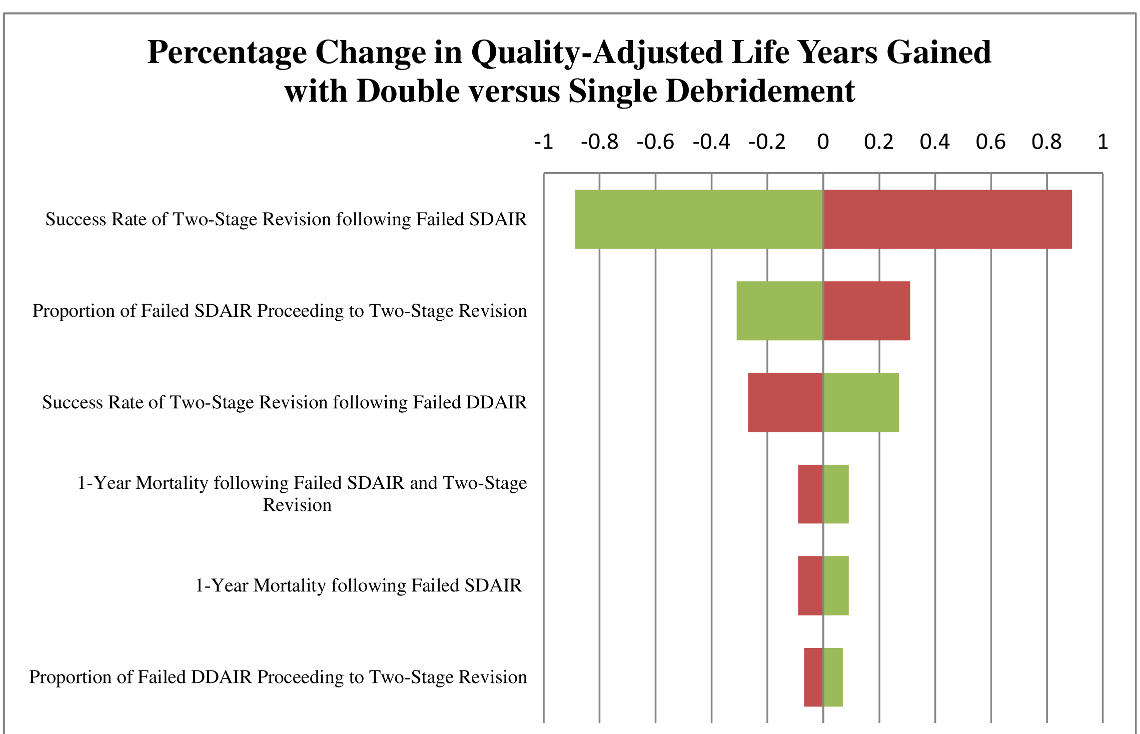

Figure 6. Tornado plot demonstrating the most sensitive parameters that influence the percentage change in quality-adjusted life years for double vs single debridement. The green and red represent if the percentage change increases or decrease as the given variable increases or decreases, respectively. D DAIR, double DAIR; S DAIR, single DAIR.

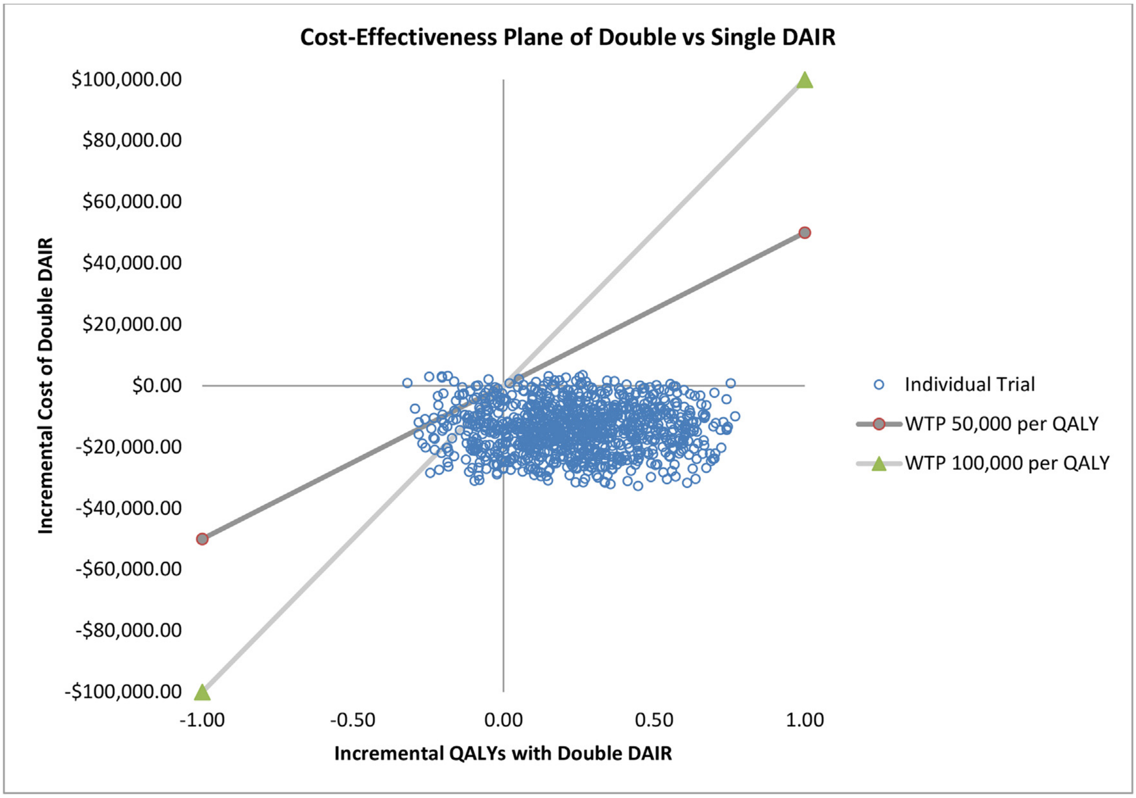

Figure 7. Cost-effectiveness plane. The y-axis is the incremental cost of the double DAIR strategy, and the x-axis is the incremental QALYs gained with double DAIR. The represented points are from the individual trials of the Monte Carlo simulation. Most points are located in the quadrant below and to the right of the willingness-to-pay (WTP) thresholds, which are deemed to be cost-effective.

using single vs planned double DAIR differ. With contemporary debridement techniques, it is possible that the success rate of single DAIR may be improving. In a study of 90 hip arthroplasties published in 2017, Bryan et al. reported a success rate of approximately 83% using single DAIR in treating acute periprosthetic infections [12]. In addition, in a more recent study by Ottesen et al. of 42 total knees with acute PJI treated with single DAIR, success rate was as high as 88% if treated within 42 days of onset of symptoms [13].

Even with these encouraging results, the recent literature for single DAIR varies considerably. In a multicenter study of DAIR across all cases of total knee PJI between 2005 and 2015, the failure of single DAIR was 57.4% [27]. Even when selecting for the optimal patients for a DAIR procedure, including no more than 1 week of symptoms (acute infection) and infection with a non-*Staphylococcus aureus* organism, the failure rate was still 39.6%. As this study notes, many factors besides acuity of the infection can influence the efficacy of DAIR in TKA PJIs, and factors including age of the implant >1 year from index surgery, cases of hematogenous infection, and infections with *Staphylococcus aureus* or gram-negative bacteria have been shown to decrease the success rates of DAIR procedures [10,29,32,64,66].

In this study, cost was assessed from a societal perspective. The planned double debridement protocol does involve a 5- to 7-day interval period between debridements. While the patient typically remains inpatient during this time, it is certainly feasible for the patient to be discharged and then readmitted for the second procedure. Because each individual hospital has a different cost structure, the cost of each night in the hospital would be impossible to accurately quantify in a way that would be generalizable. Furthermore, with most payer contracts, inpatient stays for infected TJAs are not billed on a per-day basis; these added costs are borne solely by the hospital. As a result, we have chosen to analyze costs from the payer and patient perspectives. Fortunately, infected TJAs are relatively rare, so the added cost of the extra nights would be relatively minimal compared to the cost borne by the health system if the suboptimal strategy were routinely chosen. While the short-term hospital stays are longer with the planned double debridement strategy, a higher success rate clearly decreases the number of patients proceeding to the two-stage revision which involves two subsequent hospital stays. In our study, we found that even a modest 10% increase in success rates of double vs single DAIR was cost-effective. From a societal perspective, this trade-off is clearly beneficial, although from a hospital's perspective, transitioning from a single to double DAIR approach would likely require discussion among stakeholders to make such a strategy financially acceptable.

This study has limitations. First, the results of this decision analysis are based on inputs obtained from previously published study results. As discussed previously, the success rates of DAIR procedures vary in the literature. The inputs used are averaged values of available literature but do not take host or infecting organisms into account, nor do they take into account the differences in surgical technique of a DAIR procedure. Second, owing to generally small sample sizes in each individual study, many single and double DAIR studies combine total hip and total knee acute PJIs in their analysis. As seen in Appendix A, there are also clearly many more patients in the available literature who underwent a single compared to a double debridement technique (1665 vs 169 patients, respectively). The rates of success for each technique used in this study are calculated as the mean values reported in the literature. It is certainly possible that the true rates of success are different from the mean rates used in our analysis. Strategy tables are provided to demonstrate the best- and worst-case success rates for each technique, ranging from as low as 30% success for double debridement to as high as 90% for single debridement. Third, the definitions of acute PJI vary across studies, with most studies specifying 4 weeks or 30 days from the onset of symptoms as an inclusion criterion. Similarly, there are variations with regard to antibiotic protocols, including the use of extended oral antibiotics after completion of an intravenous antibiotic course. Fourth, the current literature is mixed as to whether or not failed DAIR impacts subsequent two-stage revision success rates [37,38]. Because the answer to this question is not yet definitive, and the current literature is not controlled for single vs double DAIR, our model did not include an analysis of the impact of this variable in our model. Finally and notably, there are fewer studies using a planned double debridement strategy than those using single debridement.

Conclusions

The most cost-effective strategy for PJI in total joint arthroplasty is infection prevention, through proper patient selection and optimization, perioperative care, and prophylaxis. When infection does occur, especially in the current health-care environment, it is often challenging to justify the added cost and increased morbidity of a planned repeat procedure. Our analysis demonstrates that double debridement is cost-effective from a societal perspective if the success rate is 10% or greater than the success rate of a single DAIR. These findings should encourage future prospective research to definitively identify the optimal treatment strategy for acute PJI.

Conflicts of interest

K.J.B. is a paid consultant for Centers for Medicare and Medicaid Services, is an unpaid consultant for Harvard Business School Institute for Strategy and Competitiveness, has stock or stock options in Carrum Health, receives research support as a principal investigator from Agency for Healthcare Research and Quality (AHRQ), receives royalties from Wolters Kluwer, is in the editorial/governing board of Slack Incorporated, and is a board member in American Academy of Orthopaedic Surgeons Board of Directors. H.D.C. receives royalties from and is a paid consultant for ConforMIS and Zimmer-Biomet, is an unpaid consultant for OSSO VR, receives research support from Stryker, receives royalties from AAOS/Journal of the American Academy of Orthopaedic Surgeons, is in the editorial/governing board of JAAOS and Clinical Orthopedics & Related Research, and is a board member of AAOS, International Congress for Joint Replacement, Association of Bone and Joint Surgeons, and Knee Society. M.J.S. receives royalties from BodyCad, has stock or stock options in Sonoran Biosciences, receives research support from DePuy Synthes and Stryker, receives other financial or material support from Stryker, and is in the editorial/governing board of *Journal of Arthroplasty* and *Arthroplasty Today*. A.J.S. is in the editorial/governing board of *Arthroplasty Today* and is a board member of American Association of Hip and Knee Surgeons and Centers for Medicare and Medicaid Services.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.artd.2021.08.009.

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