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Original Research

Outcomes of Antibiotic-Impregnated Calcium Sulfate, Reamer -Irrigator-Aspirator, and Locked Intramedullary Static Spacer in the Treatment of Periprosthetic Joint Infection in the Multiply Revised and Infected Knee: A Single-Center Case Series

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A B S T R A C T

Background: Periprosthetic joint infection after total knee arthroplasty is commonly treated via 2-stage revision utilizing either articulating or static antibiotic cement spacers. While recent literature exhibits a slight functional advantage in favor of articulating spacers, those patients with a history of recurrent infection/multiple revision procedures are frequently excluded from these studies. The purpose of this study was to report infection eradication rates and efficacy of utilizing antibiotic-loaded locked intramedullary nail for infection for the multiply revised, infected total knee arthroplasty.
Methods: A retrospective review was performed of all consecutive patients receiving static spacers between 2017 and 2020 at an academic medical center. Surgical techniques for all patients included irrigation and debridement using a reamer-irrigator-aspirator, injection of antibiotic-loaded calcium sulfate into the intramedullary canal, and nail placement. Antibiotic-loaded cement is then used to create a spacer block in the joint space. A Cox proportional hazard regression was run to identify risk factors for reinfection.
Results: Forty-two knees in 39 patients were identified meeting inclusion criteria. Overall, there was an 68.8% infection eradication rate at an average of 46.9 months following spacer placement. The only risk factors identified on cox regression were increasing number of previous spacers, a surrogate for previous infections (hazards ratio = 14.818, P value = .021), and increasing operative time during spacer placement (hazards ratio = 1.014, P value = .039).
Conclusions: Use of static spacers, in conjunction with reamer-irrigator-aspirator and antibiotic-loaded calcium sulfate, can be effective in treating chronic, complex periprosthetic joint infections in the setting of bone loss and or soft-tissue compromise and produced similar results to more simple infection scenarios.

Introduction

Prosthetic knee infections have been reported to have incidence of 0.25%-2% and are currently the leading cause for failed total knee arthroplasty (TKA) within the first 2 years following the procedure [1-3]. Furthermore, infection is documented as being the diagnosis for revision or reoperation in 25%-47% of all modern TKA revision procedures [4-6]. Current treatment options for periprosthetic knee infections are 1- or 2-stage revision procedures for late or chronic infection, and debridement and implant retention for acute infections (less than 4 weeks from index surgery) [7]. In the United States, the current gold standard for treating periprosthetic knee infections is a 2-stage revision with an articulating or static antibiotic-loaded cement spacer during the interim period before replantation [3,8]. Studies have shown that 2-stage exchanges are

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highly effective in treating periprosthetic joint infection (PJI) with infection eradication rates between 59%-100% [9,10]. In addition to treating and eradicating the infection, temporary antibiotic cement spacers also help to maintain limb length and prevent muscle and soft-tissue contracture [3,11].

First described by Insall et al. [12] in 1983, 2-stage revision remains the gold standard for treating chronically infected PJIs. Once a diagnosis of infection is made, the first stage consists of explantation of all implants retained from the index procedure, the joint is irrigated and debrided and typically an antibiotic-loaded cement spacer is inserted to temporarily replace the prosthesis which delivers high concentrations of local antibiotics directly to the infected area while maintaining joint space and preventing soft-tissue contractures [13]. After infection eradication is confirmed using serial inflammatory markers and monitoring clinical symptoms, the cement antibiotic spacer is removed during the second stage, and a new prosthesis is reimplanted.

Antibiotic spacers used in the interim period between the 2-stage revision acts as a temporary prosthesis and serves multiple functions. They primarily provide local delivery of antibiotics to the infected area, preserve the joint space, and provide mechanical support by minimizing the potential for bone collapse, muscle contracture, and joint stiffness [13,14]. Antibiotic spacers are categorized into static (restricts range of motion about the knee joint) and articulating spacers (allows dynamic range of motion about the knee joint).

Static spacers are commonly indicated for patients with severe uncontrolled infections, ligamentous laxity, compromise of the extensor mechanism, severe bone loss that may have occurred during explantation of the previous implant, or deficiencies in the soft tissue layer overlaying the joint [15]. Literature have proposed that the inherent function of restricting motion around the knee joint by the static spacer provides greater relief from the inflammation and congestion, thereby facilitating the infection eradication process [14,16]. Moreover, the use of static spacers is a more cost-effective option when compared to the use of articulating type [3,17,18].

Studies evaluating the role of static vs articulating spacers used in 2-stage revisions often exclude patients who have undergone multiple revisions or have a history of recurrent infections, as the choice of spacer is influenced by patient factors and clinical situation. Although, these rare cases of complex PJIs may only be encountered in a minority of patients, they pose significant challenges; the treatment options available to the surgeon's arsenal are limited and may necessitate amputation or arthrodesis of the knee joint if the patient's condition is not amenable to further surgery. Our study aims to address these gaps in literature by assessing infection eradication rates (elevation of inflammation laboratory values requiring reoperation) in patients that underwent 2-stage revision using static spacer made from a locked intramedullary nail and antibiotic-loaded cement spacer, with minimum 2-year follow-up. We hypothesize that infection eradication rates in these high-risk patients will be comparable to previous reported rates, despite the exclusion of such patients in prior literature.

Material and methods

Data collection

Institutional review board approval was obtained prior to the initiation of the current study. Written informed consent was obtained from all patients prior to their inclusion into our adult reconstruction outcomes registry. A comprehensive retrospective review was conducted by querying our institutional adult reconstruction registry at a single academic medical center. We identified a series of multiply revised patients who underwent 2-stage revision and placement of locked intramedullary nail static spacer between October 2017 and November 2020. Patients were deemed eligible for inclusion if they were 18 years of age or older, had undergone at least 1 previous revision procedure prior to treatment with 2-stage revision for infection, and received a static locked intramedullary spacer. Patients were excluded from the study if they had not been previously revised or infected. All surgeries in this study were performed by the 2 senior authors. The primary outcome of interest was infection eradication rate, defined as total proportion of patients who did not experience reinfection. For determining reinfection, both preoperative serological markers and intraoperative soft-tissue biopsy results were utilized, in cases where reoperation was deemed necessary. Secondary outcomes aimed to determine patient factors associated with an increased risk of reinfection.

A thorough manual review of our electronic medical record, Cerner (North Kansas City, MO), was performed identifying pertinent study information. Study variables that were analyzed included eradication rate, previous number of arthroplasty procedures, previous number of spacers, number of cement bags used, pathogen isolated on culture, preoperative hemoglobin (Hgb) level, immediate postoperative Hgb levels, change in Hgb, transfusion rate (and total units of blood transfused), and follow-up time (in months). Additionally, other variables included demographic data (ie, age, gender, body mass index, American Society of Anesthesiology scores, smoking status), comorbidity data (ie, Elixhauser Comorbidity Index, Charlson Comorbidity Index), history of diabetes, alcohol use, depression, operative data (ie, surgical laterality and operative time in minutes), and postoperative data (ie, reimplantation with either revision TKA or distal femur replacement, spacer revision, and mortality). The Elixhauser Comorbidity Index establishes a reliable measure of categorizing comorbidity measures using International Classification of Diseases diagnosis codes based on administrative data.

Surgical technique

All cases were performed with the patient positioned supine on a flat radiolucent table with fluoroscopic imaging. The medial parapatellar approach was utilized, incorporating patients' previous incisions. Following the arthrotomy, a thorough synovectomy and debridement were performed in all cases, with excision of any devitalized soft tissue until normal appearing tissue was evident. Synovectomy was performed in a systematic fashion, with clearance of all devitalized tissue within the medial and lateral gutter, anterior femur, Hoffa's fat pad, femoral notch, and posterior knee. All excised tissue including necrotic, nonviable, grossly contaminated skin, subcutaneous tissue, muscle, and fascia was collected as specimen for microbiology and pathology analysis. The goal of component explantation was to preserve bone. Subsequently, saucerization of the tibial and femoral canals was performed with the Reamer-Irrigator-Aspirator (DePuy Synthes, Paoli, PA). All bony specimens collected were sent for microbiology analysis to aide in antibiotic selection. A dilute betadine wash (17cc betadine mixed with 500cc normal saline) with subsequent irrigation with pulsatile lavage using normal saline, along with chlorhexidine scrub was then performed. Calcium sulfate 20cc (Stimulan, Biocomposites Ltd., Keele, United Kingdom) impregnated with 2g vancomycin and 2.4g tobramycin was prepared as per the manufacturer's instructions and injected up the femoral canal and an additional 20cc down the tibial canal prior to insertion of the intramedullary nail. Once inserted, the nail is statically locked before the antibiotic spacer is created. The cement was manually loaded with vancomycin and tobramycin (3.0gm and 3.6gm, respectively, per bag of cement) using dosages reported in previous literature to ensure drug elution that provides adequate minimum inhibitory concentration for the common pathogens encountered in PJIs and subsequently applied in around the joints to coat the exposed portions of the intramedullary nail (Fig. 1) [19].

Postoperative protocol

Following the surgical procedure, patients were placed in a posterior long leg splint (knee immobilizer) and instructed to maintain non–weight-bearing status until explant of the antibiotic spacer and revision TKA. After the placement of the spacer, patients continued to receive culture-specific antibiotics for a duration of 6 weeks. Once the antibiotic course was completed, patients underwent an antibiotic holiday before being re-evaluated by our infectious disease colleagues for signs of persistent infection such as elevated erythrocyte sedimentation rate, C-reactive protein, and white blood cell count. For patients with laboratory markers or clinical signs of persistent infection, antibiotics were restarted, and the spacer was recharged. If the infection was cleared based on inflammatory markers, a definitive revision procedure was scheduled. Patients were considered to have eradicated the infection if they remained infection-free at the 2-year follow-up.

Statistical analysis

Descriptive statistics were reported as means ± standard deviations for continuous data and as counts (percentages) for categorical data. A Cox Proportional Hazard Regression (HR) model was used to identify risk factors associated with reinfection, and the results were reported using HR. A P value $\leq$.05 was deemed to be statistically significant a priori. All statistical analyses were conducted using SPSS, version 25 (IBM Corporation, Armonk, New York), software.

Ethics in publishing

This study was conducted in accordance with the Declaration of Helsinki and approved by WCG Institutional Review Board (protocol number: WIRB1177009). Written informed consent was obtained from all subjects involved in this study.

Results

Overall, there was an 68.8% infection eradication rate at an average follow-up of 46.9 months (range: 25 to 70 months) following static spacer placement (Table 1). Out of the 42 knees in 39 patients, 2 patients required 2 static spacers on the ipsilateral limb and were only considered once for reinfection rate. Among the remaining patients, 35 (83.3%) underwent a successful revision TKA or distal femur replacement at an average of 5.6 months following the spacer placement and 63% remained infection free. Three patients (8%) died prior to reimplantation and 7 (18%) patients died at mean 13.8 ± 9.4 months following reimplantation with TKA or distal femur replacement , all due to medical comorbidities unrelated to the static spacer placement. Seven (18%) patients necessitated a spacer revision before the reimplantation of their revision TKA: 1 (3%) patient experienced a periprosthetic fracture around the spacer, 1 (3%) patient developed a sinus tract tracking to the spacer, and 5 (13%) patients had unresolved infections at the time of revision required a revision static spacer placement. Knee stiffness was reported in 8 (21%) patients of which 2 returned to the

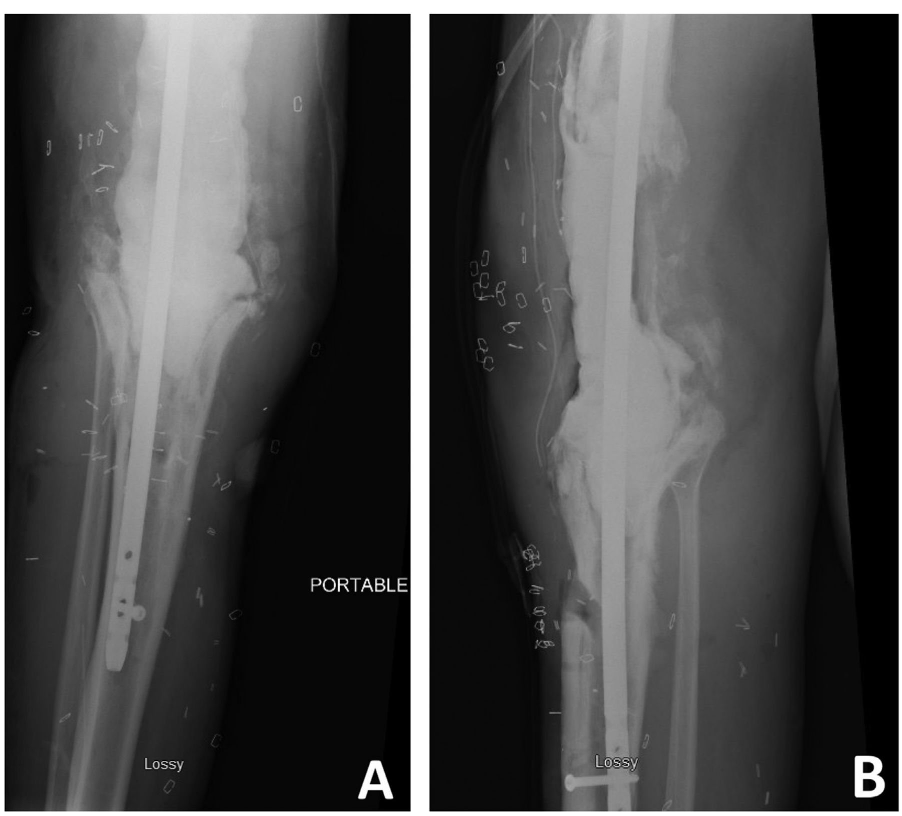

Figure 1. Immediate postoperative anteroposterior (a) and lateral (b) radiographs of a patient who has undergone multiple revision procedures treated with a statically locked intramedullary nail as an antibiotic cement spacer.

Table 1
Patient demographics.

Variables	Means (±SD) or counts (%)[a]
Total knees	42
Infection eradication rate at 2-year follow-up time point	33 (78.6 %)
Infection eradication rate at final follow-up for subjects still alive (n = 32)	22 (68.8%)
Age	69.1 ± 10.8
Gender	
Female	24 (57.1%)
Male	18 (42.9%)
BMI	30.6 ± 6.9
Laterality	
Left	22 (52.4%)
Right	20 (47.6%)
Previous # arthroplasty procedures	2.2 ± 1.1
Previous # spacers implanted	
0	30 (71.4%)
1	10 (23.8%)
2	1 (2.4%)
3	1 (2.4%)
Cement used	
0-1	0 (0%)
2	5 (12.2%)
3	14 (34.1%)
4	18 (43.9%)
5	3 (7.3%)
6	1 (2.4%)
ECI	4.1 ± 6.5
CCI	4.8 ± 2.5
ASA score	
1	0 (0%)
2	12 (29.3%)
3	24 (58.5%)
4	5 (12.2%)
Operative time (in min)	254.1 ± 110.2
Diabetes	13 (31.0%)
Alcohol use	2 (4.8%)
Smoking	9 (21.4%)
Depression	13 (31.0%)
Transfusion	25 (61.0%)
Units transfused	
0	16 (39.0%)
1	2 (4.9%)
2	14 (34.1%)
3	2 (4.9%)
4	2 (4.9%)
5	2 (4.9%)
6+	3 (7.3%)
Subgrouped analysis:	
Preoperative hemoglobin levels ($P = .15$)	
Transfused	10.1 ± 1.2
Nontransfused	10.6 ± 1.8
Immediate postoperative hemoglobin levels ($P = .076$)	
Transfused	7.8 ± 1.7
Nontransfused	8.5 ± 1.3
Change in hemoglobin levels ($P = .583$)	
Transfused	2.3 ± 1.0
Nontransfused	2.1 ± 1.6
Follow-Up Time (in months)	39.2 (range: 1.8-70)
Follow-Up Time (in months) for subjects still alive	46.9 (range: 25-70)

ASA score, American Society of Anesthesiology score; BMI, body mass index; CCI, Charlson Comorbidity Index; ECI, Elixhauser Comorbidity Index; SD, standard deviation.

[a] Not all counts sum to sample total due to missing data for some variable.

operative room to address the knee contraction. One patient underwent manipulation under anesthesia and the second patient required lysis of adhesion and polyethylene component exchange. The remaining 6 patients were deemed poor surgical candidates and were managed conservatively with continuous passive motion machines and continued physical rehabilitation.

Due to the high rate of patients requiring transfusion, subanalysis comparing patients that required transfusion vs those that did not found that patients requiring transfusion trended toward having lower preoperative Hgb levels (10.1 ± 1.2 vs 10.6 ± 1.8, $P = .15$). Immediate postoperative Hgb levels also trended lower in the transfused patients (7.8 ± 1.7 vs 8.5 ± 1.3, $P = .076$), however, the change in Hgb levels from preoperative to immediate postoperative was similar between the 2 subgroups (transfused group = 2.3 ± 1.0 vs nontransfused group = 2.1 ± 1.6, $P = .583$).

The Cox Proportional HR regression analysis identified 2 significant risk factors for failed eradication of infection: an increasing number of previous spacers as a surrogate for previous infections (HR = 14.818, $P = .021$), and increasing operative time during spacer placement (HR = 1.014, $P = .039$) as detailed in Table 2. No additional patient factors that increased the risk of reinfection were identified.

Discussion

Prosthetic knee infections are devastating complications of TKA that can have significant medical and financial consequences for patients and hospitals. Current treatment options for PJI include single-stage revision, two-stage revision with antibiotic-loaded cement spacers, or a debridement and implant retention procedure for acute infections. The gold standard is the 2-stage revision using articulating or static spacers for infection eradication prior to reimplantation of the new prosthesis. Although previous studies have shown comparable success rates in infection eradication between spacer types, improved postoperative functional scores have been reported when using articulating cement spacers [17,20-23]. However, there are gaps in literature comparing infection eradication rates between spacer types in multiply infected vs initially infected prosthetic knees; especially in cases where some infections are not amenable to articulating spacers due to severe bone loss and/or soft-tissue compromise [24]. It is crucial to continue expanding the knowledge base in this area to further improve treatment options. Thus, this study aimed to examine and compare a more complicated (ie, mega-defect, soft-tissue loss, multiply-revised) infection scenario treated with a statically locked retrograde intramedullary nail spacer with antibiotic-loaded cement to the less-complicated patients found in the literature as current historical controls.

Although further research is needed, literature has shown the efficacy of using synthetic calcium sulfate loaded with antibiotics as an adjuvant in PJI revision cases to prevent biofilm formation and is standard of care in use by the senior surgeons at this institution [25-30]. The rationale for utilizing is the advantage of being completely biodegradable and provides enhanced duration of drug elution of the incorporated antibiotics compared to acrylic cement spacers [26]. In our approach, the primary goal is to perform a definitive revision TKA after static spacer placement and infection eradication. However, for select rare cases where optimization for subsequent surgery cannot be achieved from an infection or patient's co-morbidity standpoint, particularly in our cohort of patients with extensive revision histories, the biodegradable nature of calcium sulfate loaded antibiotics offers a contingency plan as the antibiotic spacer has the capacity to be completely reabsorbed [26,28,31,32].

Nahhas et al [17] conducted a randomized control trial comparing static and articulating spacers for treatment of infected total knee arthroplasties. This was one of the first randomized controlled studies performed and their results were consistent with prior meta-analyses and comparative studies, reporting significantly greater range of motion (mean difference of 13 degrees) and

Table 2
Cox regression for reinfection.

Variables	Hazard ratio (HR)	*P* value
Age	1.15	.23
Gender	0.127	.289
BMI	0.883	.178
Previous # arthroplasty procedures	0.615	.433
Previous # spacers implanted	**14.818**	**.021**
Cement used	0.487	.287
ECI	1.004	.987
CCI	0.556	.445
ASA score	4.817	.315
Operative time	**1.014**	**.039**
Diabetes	6.965	.224
Alcohol use	18.982	.21
Smoking	1.171	.924
Depression	0.664	.835
Transfusion	0.124	.211

ASA score, American Society of Anesthesiology score; BMI, body mass index; CCI, Charlson Comorbidity Index; ECI, Elixhauser Comorbidity Index.
Statistically significant associations are bolded.

trended toward lower rates of reinfection (4.0% compared to 8.3% in the static spacer group). However, it should be noted that their study excluded patients that had been previously revised for any reason. In contrast, our study focused on multiply infected and previously revised patients, which may pose greater treatment challenges. Despite these challenges, our use of static antibiotic cement spacers with adjunct reamer-irrigator-aspirator saucerization combined with placement of intramedullary antibiotic-loaded calcium sulfate was effective in eradication of infection in 69% of our patients.

There is a paucity of literature regarding antibiotic spacers utilizing intramedullary nailing. However, Kotwal et al [33] in 2012 published their series on 58 patients with a mean follow-up of 29.4 months, who received a static spacer using a similar construct to what the senior surgeons used in this study. All patients in their series had compromised soft tissues, however, only included patients with a previous index TKA (average time for confirmation of infection was 15.5 months) necessitating a static spacer construct. Reinfection rates were higher in our study cohort compared to Kotwal et al's cohort (31.2% vs 16.2%, respectively); however, the reimplantation rate was higher in our cohort (83.3% vs 63.8%, respectively) and our study have greater follow-up times. Haleem et al [34] in 2004 published a long-term follow-up (median 7.2 years) case series on 94 patients managed with static spacer to evaluate risks of long-term reinfection rates and implant survivorship. However, the authors included patients with a history of one index TKA with a mean time from index procedure to resection arthroplasty reported to be 26.2 months. At a minimum follow-up of 2 years, the authors reported 9% reinfection rate requiring component removal and 6% requiring reoperation for mechanical loosening. Furthermore, the authors' estimated 10-year survivals, free of reoperation for infection in their cohort were 91.1% in patients without immunocompromise and 75.3% in those with immunocompromise. However, of the 5 patients that were revised with an additional 2-stage revision, they were infection free at the final follow-up. Although our study report higher reinfection rates at the 2-year time point (21.4%) in comparison to previous case series on the use of static spacers, it is important to underscore that our study had included patients that had a history of multiple revisions, indicative of a more complicated clinical prognosis and showed comparative infection eradication rates. This demonstrates that static spacers with intramedullary nail construct are a reasonably effective option for infection eradication in patients with soft-tissue and bony compromise.

Due to the unique patient selection criteria in our study, a risk analysis for reinfection was conducted using Cox Proportional HR regression analysis as shown in Table 2. Patients who had a greater number of previous static spacer implanted had a substantially higher hazard ratio of reinfection. This association indicates that the complexity of the surgical history and the number of previous infections may impact the risk of reinfection. This is consistent with previous literature that found the number of previous surgeries and number of previous infections in the same joint as a significant predictor of failure following 2-stage revision TKA [16,35]. Moreover, another significant risk factor that was identified was the operative time during the first stage of the revision where the static antibiotic spacer was placed. However, it is important to note that the 2 significant associations that were found may be confounded due to the complexity of the revision surgery. As the number of previous antibiotic spacer procedures increases, the anatomic complexity due to scarring and tissue damage may complicate the exposure and may prolong the overall operative time.

Several systematic reviews [3,21,22] and meta-analyses [8,36,37] have evaluated studies comparing clinical outcomes after static or articulating spacers in two-stage revision TKA. Of the review articles published within the past decade, the total number of static spacer patients ranged between 256 and 1511 compared to 236-2739 articulating spacer patients. With regard to reinfection rate the static spacer patients ranged 9.7%-13.6% compared to 7.9%-9% for articulating spacers [3,21,22,36]. Fiore et al [36] found a significantly lower pooled reinfection rates when articulating spacers were used (articulating = 9% vs static = 12.4, $P = .001$); however, further meta-analysis of comparative studies found no statistically differences ($P = .530$). Static spacers are commonly indicated for patients with severe uncontrolled infections, deficiencies in the soft tissue layer overlaying the joint, severe bone loss that may have occurred during explantation of the previous implant, ligamentous laxity, or compromise of the extensor mechanism.

Guild et al [3] conducted a sub-analysis evaluating reinfection rates on studies that subgrouped based on complex cases (positive culture involving virulent organisms, significant bone loss or presence of a draining sinus tract) and reported reinfections rates of 28.2% for static spacers compared to 8.4% for articulating spacers. This greater difference in reinfection rates between the 2 treatment options was attributed to the more challenging and complex nature of cases that were managed with static spacers, such as the infections with more resistant organisms, significant bone loss, or the presence of draining sinus tract. When comparing reinfection rates to previous literature which did not have stringent inclusion and exclusion, it is evident that in complex PJI scenarios whereby static spacers are used, there is a much higher inherent risk for failure compared to patients amenable to articulating spacers. Although, Guild et al.'s study definition of complex cases did not include a history of multiple revisions due to infection, the incidence of reinfection of 28.2% for patients treated with static spacers were similar to the rates found in this current study at 31.2%. Regarding postoperative functional outcomes, every review article previously mentioned [3,8,21,22,36-38] unanimously reported significantly higher postoperative range of motion when patients were treated with articulating spacers, and 1 meta-analysis [8] reported a mean difference of 12.19 degrees of knee flexion at final clinical follow-up. However, patient-reported outcome scores including hospital for special surgery knee rating scale and knee society score revealed, comparable final follow-up scores.

PJI continues to be a significant issue in the orthopedic community, evidence suggests infection control has not improved over time [39]. Several risk factors increase the likelihood repeat infections or failed reimplantation, including female gender, heart disease, and psychological disorders [40,41]. Additionally, culture-negative infections, which have been shown to increase reinfection risk by 4-fold, are common in the multiply revised or previously treated patient population [42]. This highlights the complexity and challenges of treating multiply revised patients. Many comparison studies of static vs articulating spacers commonly exclude multiply revised patients or cite their limitations of selecting more complex cases to be revised with a static spacer. Attempts at subgrouping patients based on preexisting bone loss (using Anderson Orthopedic Research Institute classification) at the time of explant and insertion of spacer revealed that static spacers were preferentially placed in patients with greater femoral bone loss [3]. However, there is a lack of comparative studies that account for other factors such as soft-tissue viability and quality, the confirmed microorganism, medical comorbidities, number of previous PJI diagnoses and revisions [36]. Despite the significant amount of risk factors present in our patient cohort, we demonstrated infection eradication rates comparable to what is reported in the literature for less complicated patient population.

This study is limited by its retrospective nature as patients were not randomized, rather our inclusion criteria for static spacers were based on patients with a history of being multiply infected or multiply revised, which may not be representative of all patients with PJIs. As a result, there was no head-to-head patient comparison, but rather comparison to a historical literature control with a less complicated patient cohort. Furthermore, the sample size was limited by the strict criteria of only including patients with previous multiply revised TKAs due to infection and thus may have influenced the reliability of the results and achieving adequate power to detect significant associations. Future studies should focus on conducting a multicenter prospective studies with adequate number of patients and can further evaluate cost comparison analysis, taking into account price of implant, hospital length of stay, and post discharge care (ie, physical therapy, discharge disposition, and so on) which would provide value in elucidating the economic impact of utilizing static spacers with intramedullary nailing.

Conclusions

Prosthetic knee infections are serious complications of TKA that can lead to devastating physical and financial effects both to the patient and to the hospital system. Thus, it is important to assess the efficacy of antibiotic-loaded cement spacers in eradicating infections. This study demonstrates that the use of static spacers, in conjunction with reamer-irrigator-aspirator and antibiotic-loaded calcium sulfate, can be effective in treating chronic, complex PJIs in the setting of bone loss and or soft-tissue compromise, and produced similar results to more simple infection scenarios. Due to these results, reamer-irrigator-aspirator and the addition of antibiotic-loaded calcium sulfate are now a standard protocol at our institution for 2-stage treatments of infection, regardless of spacer type. This approach has the potential to improve patient outcomes while also reducing the healthcare burden associated with managing prosthetic knee infections.

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Conflicts of interest

Ian S. Hong is a paid biostatistical consultant for LifeNet Health. Richard S. Yoon is a board member/committee appointments for American Association of Hip and Knee Surgeons, Foundation for Physician Advancement, Foundation of Orthopaedic Trauma, and Orthopaedic Trauma Association; received research support from Organogenesis, Center of Orthopaedic Trauma Advancement, OMeGA, NIH, Biocomposites, WrightTornier, Biomet, LifeNet Health, and Synthes; is a paid consultant for Arthrex, Depuy, LifeNet Health, OrthoGrid, ORTHOXEL, SI-BONE, Stryker, Synthes, and Use-Lab; is a part of speakers bureau for Horizon Therapeutics. Frank A. Liporace is an unpaid consultant for AO; is a paid consultant for Biomet and Synthes; received royalties from Biomet and Wright Medical Technology, Inc; and is a part of speakers bureau for Biomet and Synthes. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Jaclyn M. Jankowski: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Luke G. Menken:** Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Filippo Romanelli:** Writing – original draft, Validation, Methodology, Investigation. **Ian S. Hong:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Alex Tang:** Writing – original draft, Project administration, Data curation. **Richard S. Yoon:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Frank A. Liporace:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

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