Antibacterial hydrogel coating is associated with lower complication risks after complex high-risk primary and cementless hip revision arthroplasty

a retrospective matched cohort study

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Aims

This study aimed to verify the hypothesis that an antibiotic-loaded hydrogel, defensive antimicrobial coating (DAC), reduces overall complication and infection rates when used for high-risk primary and revision total hip arthroplasty (THA).

Methods

This was a retrospective, 1:1 matched cohort study of 238 patients, treated with cementless implants coated with and without DAC. A subgroup analysis was also conducted of patients undergoing second-stage revision THA for periprosthetic joint infection (PJI). Reinfection rates within two years, complications necessitating surgical intervention, and radiological analysis for aseptic loosening were assessed.

Results

Overall, the mean age of the patients was 68.3 years (SD 11.5), with 39 (32.8%) McPherson class A, 64 (53.8%) class B, and 16 (13.4%) class C. Four (3.4%) patients in the DAC group developed complications including one PJI and one delayed wound healing, while 13 (10.9%) patients in the control group developed complications, including five PJIs and three delayed wound healing ($p = 0.032$). PJI rates ($p = 0.136$) and delayed wound healing rates ($p = 0.337$) were not statistically significant. For second-stage revision THA, for PJI there were 86 patients in the DAC group and 45 in the control group. One patient (1.2%) in the DAC group developed complications with no recurrences of infection or delayed wound healing, while ten patients (22.2%) in the control group developed complications including four recurrent PJI and one delayed wound healing ($p = 0.003$). Recurrent PJI rates were statistically significant ($p = 0.005$), while delayed wound healing rates were not ($p = 0.165$). Patients treated with DAC also had lower rates of aseptic loosening (0% compared with 6.7%; $p = 0.015$). No local or systemic side effects related to the DAC hydrogel coating were observed.

Conclusion

Antibiotic-impregnated hydrogel coatings on cementless implants appear to be associated with decreased complication rates after complex primary or revision THA. For second-stage revision THA for PJI, it is also associated with reduced risk of reinfection and aseptic loosening.

Take home message

- Antibiotic-impregnated hydrogel coatings on cementless implants appear to be associated with decreased complication rates after complex primary or revision total hip arthroplasty (THA).

- For second-stage revision THA for periprosthetic joint infection, antibiotic-impregnated hydrogel coating is associated with reduced risk of reinfection and aseptic loosening.

Introduction

Periprosthetic joint infection (PJI) remains one of the primary causes of failure in total hip arthroplasty (THA), with increasing incidence as evidenced by numerous studies and registry data.[1] These infections not only lead to higher morbidity and mortality rates, but also pose a substantial cost burden for public health systems.[2] The risk of post-surgical infection is even greater for second-stage revision THA for PJI, with reinfection rates that may exceed 10% due to suboptimal diagnostic and treatment strategies.[3] Cemented hip arthroplasties using antibiotic-loaded cement have been reported to reduce rates of deep infection,[4] and have historically been advocated for use in revision THA for PJI due to the ability to elute high doses of antibiotics locally. However, there is no clear consensus regarding implant fixation choice for revision THA,[5] due to the myriad of benefits associated with the use of cementless stems such as long-term osseointegration,[6] reduction in operating time and its associated morbidity, obviating risk of bone cement implantation syndrome (BCIS),[7] and facilitating explant with fewer difficulties without the need to remove cement in the event of recurrent infection.[8]

Various methods to deliver high doses of local antibiotics have been explored to reduce the risk of recurrent infection in revision THA. Antibiotic-impregnated absorbable beads embedded in the joint or soft-tissue have been associated with increased wound drainage, hypercalcaemia, and a theoretical risk of third body wear.[9] In addition, it does not confer protection over the implant surface, which is most vulnerable to bacterial adhesion and biofilm formation.[10] Antibiotic-laden coatings, applied during surgery rather than built into the device, allow direct targeted and synergistic antibacterial and antiadhesive properties to prevent bacterial adhesion to the implant. Defensive antibacterial coating (DAC; Novagenit, Italy) is an antibacterial hydrogel coating composed of hyaluronan and poly-D, L-lactide that has shown promising outcomes, including a reduction in the incidence of early post-surgical infection rates after osteosynthesis and arthroplasty.[11]

This study aimed to compare complication rates, including PJIs, in patients with high-risk for infection after primary and revision cementless hip arthroplasty with and without the use of DAC-coated implants. As a secondary endpoint, subgroup analysis of DAC usage in second-stage cementless revision for prior PJI was evaluated. We hypothesized that application of DAC reduces the risk of postoperative infection and is not associated with increased adverse events.

Methods

Study design and population

The study was conducted in accordance with the principles of the Helsinki Declaration,[12] and obtained approval from the local ethics board. All patients gave informed consent for data collection and analysis.

This was a retrospective matched cohort study using data from a prospectively collected institutional hip and knee arthroplasty registry. All patients undergoing high-risk primary or revision hip arthroplasty using cementless implants and DAC from January 2015 to January 2022 were included. A 1:1 matching of cementless hip arthroplasties without DAC, from a contemporaneous time period, was conducted based on age and McPherson classification[13] at time of definitive surgical intervention. Surgical techniques, implant choices, and antibiotic treatment strategies remained unchanged during this time period.

Inclusion criteria included all patients undergoing high-risk primary hip arthroplasty, defined as THA in patients with considerable systemic, soft-tissue, or bony compromise,[14] previous joint infection or infected hardware, and revision THA. For subgroup analysis, prosthetic hip infection as defined by the 2018 Musculoskeletal Infection Society (MSIS) criteria,[15] treated with a two-stage procedure using cementless hip revision implants, was evaluated for difference in outcomes with or without DAC. Patients in whom cemented hip implants were used, large soft-tissue defects that were not amenable to primary skin closure, incomplete data, or less than two years of follow-up were excluded from the study. The patient recruitment flowchart is shown in Figure 1.

Patient demographics

A total of 119 patients underwent primary or revision THA with cementless components and application of DAC, and were matched against 119 patients who underwent primary or revision THA with cementless components without DAC application. The mean age was 68.3 years (SD 11.5), and there were 39 (32.8%) McPherson type A hosts, 64 (53.8%) type B hosts, and 16 (13.4%) type C hosts in both groups. There were 55 (46.2%) males and 60 (53.8%) females in the DAC group, while the control group had 60 (50.4%) males and 59 (49.6%) females ($p = 0.517$, chi-squared test). The mean follow-up length in the DAC group was shorter than in the control group: 3.2 years (SD 1.1) compared with 4.2 years (SD 2.4), respectively ($p = 0.001$, logistic regression). In the DAC group, there were 13 primary THAs, 14 aseptic single-stage revisions, six single-stage revisions for PJI, and 86 second-stage revision THAs for PJI. In the control group, there were nine primary THAs, 48 aseptic single-stage revisions, ten single-stage revisions for PJI, seven debridement, antibiotics, and implant retentions (DAIR) procedures, and 45 second-stage revision THAs for PJI. Patient demographics, duration of follow-up, diagnoses, and type of surgery performed for the entire cohort are shown in Table I.

Surgical treatment and DAC preparation

All patients underwent routine preoperative workup, including an anaesthetic assessment and optimization of risk factors such as diabetes mellitus and smoking prior to surgical intervention. All hip arthroplasties were performed using the posterior approach, and the cementless prosthesis was implanted according to the surgeon's discretion depending on bone stock and implant availability. Second-stage revision hip arthroplasties for PJI were performed at least eight weeks after index surgery to explant the infected prosthesis, debride, and insert an antibiotic-loaded spacer (StageOne, Zimmer Biomet, USA; or Vancogenx-Space, TECRES, Italy). The explanted prostheses and periprosthetic tissue were sent for microbiological cultures and analyses.

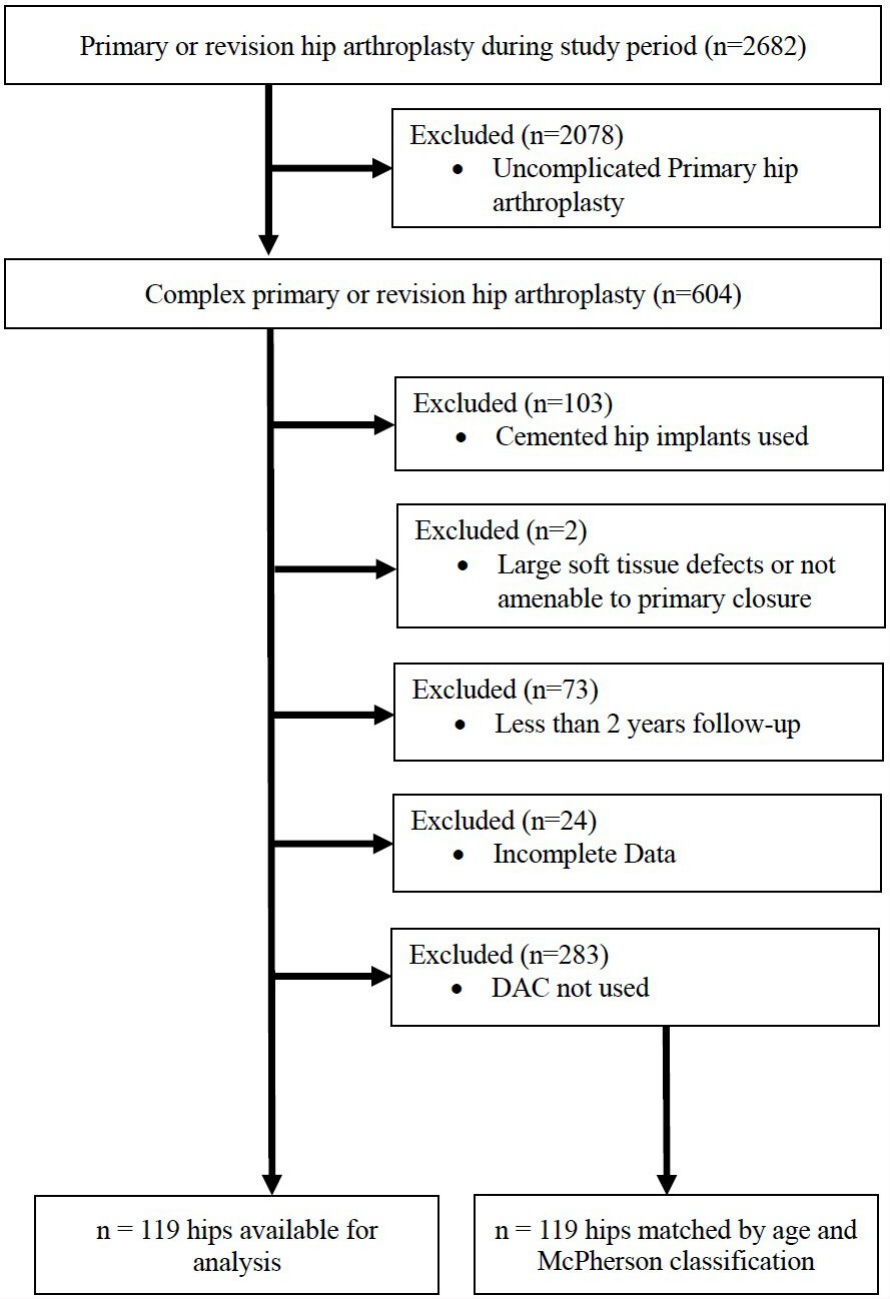

Fig. 1
Patient recruitment flowchart. DAC, defensive antimicrobial coating.

The DAC hydrogel was prepared during the surgery as per the manufacturer's instructions. A syringe containing 300 mg of sterile DAC powder was mixed with 5 ml of sterile water and the antibiotic of choice. For second-stage revision hip arthroplasty for PJI, the specific antibiotic used varied based on microbiological cultures obtained during the first stage of the procedure. When the pathogen causing the infection was unknown, vancomycin alone, or a combination of meropenem and vancomycin were the preferred choices. Five minutes after mixing, the DAC hydrogel was applied directly to the implant surfaces of both the acetabular and femoral components. The entire outer implant surface, including the parts external to the bone and any fixation screws used, were covered with the hydrogel. The implants were then implanted using standard surgical techniques, as per surgeon preference.

All patients received prophylactic antibiotics prior to skin incision. Systemic antibiotic therapy was continued until postoperative microbiological cultures returned negative, or for a minimum of two weeks after surgery in second-stage procedures for PJI. For patients undergoing debridement, antibiotics, and implant retention (DAIR) surgery, broad spectrum antibiotics were continued after surgery until microbiological sensitivities were obtained before converting to targeted intravenous (IV) and oral antibiotics. The duration of antibiotics was dependent on clinical and biochemical progression. Low-molecular-weight heparin was given for five weeks for deep vein thrombosis prophylaxis according to hospital protocols.

Table I. Patient demographics, duration of follow-up, diagnoses, and surgery type performed.

Baseline characteristic	**With DAC** (n = 119)	**Without DAC** (n = 119)	p-value
Mean age, yrs (SD)	68.3 (11.5)		0.999*
McPherson classification, n (%)			
A	39 (32.8)		
B	64 (53.8)		
C	16 (13.4)		0.999*
Sex, n (%)			
Male	55 (46.2)	60 (50.4)	0.517†
Female	60 (53.8)	59 (49.6)	
Mean follow-up duration, yrs (SD)	3.2 (1.1)	4.2 (2.4)	0.001*
Diagnosis, n (%)			
Osteoarthritis	13 (10.9)	9 (7.6)	N/A
Septic arthritis	3 (2.5)	0 (0.0)	
Periprosthetic fracture	2 (1.7)	1 (0.8)	
ARMD	0 (0.0)	5 (4.2)	
Aseptic loosening	12 (10.1)	42 (35.3)	
PJI	89 (74.8)	62 (52.1)	
Type of surgery performed, n (%)			
Primary THA	13 (10.9)	9 (7.6)	N/A
Single-stage revision (aseptic)	14 (11.8)	48 (40.3)	
Single-stage revision (septic)	6 (5.0)	10 (8.4)	
DAIR	0 (0.0)	7 (5.9)	
Second-stage revision THA	86 (72.3)	45 (37.8)	

*Logistic regression.
†Chi-squared test.
ARMD, adverse reaction to metal debris; DAC, defensive antimicrobial coating; DAIR, debridement, antibiotics, and implant retention; N/A, not applicable; PJI, periprosthetic joint infection; THA, total hip arthroplasty.

Outcome measures

The primary outcome of the study was the rate of postoperative PJI after primary and revision hip arthroplasty, as defined by the MSIS criteria,[15] recurring within two years after second-stage revision surgery for PJI, as defined by the International Multidisciplinary Consensus Meeting.[16] Secondary outcomes included substantial surgical complications including delayed wound healing, prosthetic joint dislocation, and periprosthetic fractures, which were also recorded. Delayed wound healing was defined as an incomplete closure and epithelization of the wound four weeks after surgery, or the presence of wound necrosis, dehiscence, or increased exudates, which may require additional medical treatment without surgical intervention.[17] Radiographs from interval follow-ups were examined for implant loosening as defined by component migration, component fracture, osteolysis, and progression of radiolucent lines (> 2 mm) around the femoral Gruen zones or acetabular DeLee and Charnley zones.[18] Adverse outcomes including systemic anaphylaxis, acute renal or liver failure, and local skin and soft-tissue reactions were additionally recorded for patients in the DAC group during their hospital stay.

Statistical analysis

An a priori power analysis was conducted using G*Power[19] to assess the difference between two independent groups using a two-tailed test, α (α = 0.05) and power (1-β = 0.80). An estimated sample size of 158 participants with two equally sized groups of 79 participants was required to achieve a power of 0.80.

Patient demographics were summarized using descriptive analyses, with categorical data represented in frequencies and percentages. Shapiro-Wilk coefficient (W) was calculated to assess if continuous data were normally distributed with significant skew defined as $p < 0.05$. Means and SDs are presented for continuous data. Chi-squared tests were used to test for statistical significance for categorical data, $p < 0.05$. For continuous data, logistic regression analysis was used to assess for statistical significance, two-sided $p < 0.05$. All analyses were performed with SPSS version 21 (IBM, USA).

Results

Patients with hip arthroplasties performed without DAC were 3.5-times more likely to develop complications after surgery (13 patients (10.9%) compared with four patients (3.3%); p = 0.032, logistic regression). Some patients developed multiple complications after surgery; three of the patients had delayed wound healing and concurrent PJI, one patient had both a PJI and postoperative dislocation, and one patient had postoperative dislocation and a periprosthetic fracture. In total, there were 18 complications in 13 patients in the control group. THAs performed without DAC were 5.2 times more likely to develop PJI or reinfections postoperatively (four patients (3.3%) compared with one patient (0.8%)); the difference was, however, not statistically significant (p = 0.136, logistic regression). In the DAC group, there was a single case of PJI after single-stage revision surgery for aseptic loosening, which was subsequently treated with a DAIR procedure, with the pathogen isolated to be *Staphylococcus capitis*. In the control group, there were four reinfections after second-stage revision for PJI with the pathogens isolated shown to be *Staphylococcus epidermidis* in two patients, one *S. capitis*, and one methicillin-resistant *Staphylococcus aureus* (MRSA). In the DAC group, there was a single case of delayed wound healing while the control group had three cases of delayed wound healing (one patient (0.8%) compared with three patients (2.5%), odds ratio (OR) 0.32 times; p = 0.337, logistic regression). There were no local or systemic adverse events directly related to DAC use. At final follow-up, there were no incidents of aseptic loosening in the DAC group, while there were four incidents in the control group (zero patients (0.0%) compared with four patients (3.4%); p = 0.044, logistic regression). There were fewer prosthetic joint dislocations (two patients (1.7%) compared with four patients (3.4%); p = 0.417) and a lower rate of periprosthetic fractures (zero patients (0.0%) compared with two patients (1.7%); p = 0.996, both logistic regression) in the DAC group, but the differences were not statistically significant. None of the patients developed Brooker 3 or 4 heterotrophic ossification[20] requiring further surgical intervention. The complication rates and microbiological specimens isolated from the different surgeries are shown in Table II.

Table II. Complication rates for all patients and breakdown of microbiological specimens obtained from intraoperative cultures. All data shown as n (%).

Complication	With DAC (n = 119)	Without DAC (n = 119)	p-value*
Patients with post-op complications	4 (3.4)	13 (10.9)	0.032
Periprosthetic joint infection	1 (0.8)	4 (3.3)	0.241
Delayed wound healing	1 (0.8)	3 (2.5)	0.337
Aseptic loosening	0 (0.0)	4 (3.4)	0.044
Dislocation	2 (1.7)	4 (3.4)	0.417
Periprosthetic fracture	0 (0.0)	2 (1.7)	0.996
Microbiological specimens, n			N/A
Staph group	55	35	
MRSA	11	8	
Streptococci group	8	6	
Gram-negative	2	2	
Anaerobes	12	4	

*Logistic regression.
DAC, defensive antimicrobial coating; MRSA, methicillin-resistant *Staphylococcus aureus*.

For second-stage revision THA after PJI, 86 procedures were performed with and 45 performed without DAC coating of cementless implants. In this subgroup, the mean age of the DAC group was 67.2 years (SD 11.0) compared to 64.4 years (SD 12.2) in the control group (p = 0.181, logistic regression). There were 29 (33.7%) McPherson type A hosts, 47 (54.7%) type B hosts, and ten (11.6%) type C hosts in the DAC group compared to 15 (33.3%) type A, 25 (55.6%) type B, and five (11.1%) type C hosts in the control group (p = 0.994). There were 43 (50%) males and 43 (50%) females in the DAC group, while the control group had 25 (55.6%) males and 20 (44.4%) females (p = 0.546, logistic regression). The mean follow-up length in the DAC group was shorter than in the control group (3.2 (SD 1.0) compared with 5.0 years (SD 2.8); p = 0.001, logistic regression).

Patients undergoing second-stage revision THAs performed without DAC were 24.3 times more likely to develop complications after surgery (ten patients (22.2%) compared with one patient (1.2%); p = 0.003, logistic regression). THAs performed without DAC were also more likely to develop reinfections postoperatively (four patients (8.9%) compared with zero patients (0.0%); p = 0.005, logistic regression). One of the patients in the control group had both delayed wound healing and a PJI. In the DAC group, there were no cases of delayed wound healing, while the control group had one case of delayed wound healing (zero patients (0.0%) compared with one patient (2.2%); p = 0.165, logistic regression). At final follow-up, there were no incidents of aseptic loosening in the DAC group, while there were three incidents in the control group (zero patients (0.0%) compared with three patients (6.7%); p = 0.015, logistic regression). There was one prosthetic joint dislocation in each group (one patient (1.2%) compared with one patient (2.2%); p = 0.644) and a lower rate of periprosthetic fractures (zero patients (0.0%) compared with two patients (4.4%); p = 0.997, both logistic regression) in the DAC group, but the differences were not statistically significant. The patient demographics, complication rate, and antibiotic loaded into DAC for second-stage revision THA after PJI are shown in Table III.

Discussion

To our knowledge, this study represents the largest comparative study investigating the efficacy and safety profile of an antibacterial hydrogel coating with cementless implants for high-risk primary and revision THA. As the demand for THA increases, PJI rates are expected to scale up proportionally, resulting in considerable morbidity and healthcare burden.[1,21] For PJI and revision THA, the risk is even greater, with studies reporting reinfection rates for one-stage revision at 12.7%, up to 18% for two-stage revision,[22,23] and registries showing

Table III. Subgroup analysis of patients who underwent second-stage revision total hip arthroplasty for periprosthetic joint infection.

Baseline characteristic	**With DAC** (n = 86)	**Without DAC** (n = 45)	p-value
Mean age, yrs (SD)	67.2 (11.0)	64.4 (12.2)	0.181*
McPherson classification, n (%)			
A	29 (33.7)	15 (33.3)	0.546*
B	47 (54.7)	25 (55.6)	
C	10 (11.6)	5 (11.1)	
Sex, n (%)			
Male	55 (46.2)	60 (50.4)	0.517†
Female	60 (53.8)	59 (49.6)	
Mean follow-up duration, yrs (SD)	3.2 (1.0)	5.0 (2.8)	0.001*
Complications, n (%)			
Patients with post-op complications	1 (1.2)	10 (22.2)	0.003*
Periprosthetic joint infection	0 (0.0)	4 (8.9)	0.005*
Delayed wound healing	0 (0.0)	1 (2.2)	0.165*
Aseptic loosening	0 (0.0)	3 (6.7)	0.015*
Dislocation	1 (1.2)	1 (2.2)	0.644*
Periprosthetic fracture	0 (0.0)	2 (4.4)	0.997*
Antibiotic loaded into DAC, n (%)			
Vancomycin 5%	67 (77.9)		N/A
Vanco 5% + Meropenem 5%	10 (7.2)		
Vanco 5% + Rifampicin 5%	3 (3.5)		
Vanco 5% + Gentamicin 5%	1 (1.2)		
Teicoplanin 5%	3 (2.5)		
Ceftazidime 5%	1 (1.2)		
Daptomycin 5%	1 (1.2)		

*Logistic regression.
†Chi-squared test.
DAC, defensive antimicrobial coating; N/A, not applicable.

re-revision rates of 30% within one year after septic revision THA.[24] A recent study has, however, shown that with aggressive debridement and high local concentrations of targeted antibiotics, prolonged systemic antibiotics may no longer be necessary to ensure successful outcomes.[25]

Yoon et al[26] reported, in a meta-analysis of prospective studies, that the overall PJI rate after THA was significantly lower in the cementless group (0.3%, compared to 0.5% in the cemented group). While controversial, the higher rate of infection could potentially be due to longer surgical duration, which confers the highest risk of surgical site infection (SSI), especially in arthroplasty.[27] In addition, the bone cement may also induce local areas of necrosis from thermal emission or remnant monomer-induced chemical toxicity, or result in pseudo-membrane formation over the cement-bone interface that predisposes to infection.[28] Coupled with the risks of BCIS, pulmonary embolism,[29] absence of cement interdigitation in the revision setting, and added complexity of removing well-fixed cement for further revisions,[30] uncemented implants provide an attractive option for revision THA, especially in younger patients where implant longevity and bone preservation is desired.

Different strategies have been implemented to mitigate PJI risks to varying degrees of success. Gristina et al[10] first described the "race for the surface" phenomena, where the body's innate immune system competes against bacterial cells to colonize implant surfaces in the critical first few hours after implantation. Bacterial colonized implants become enveloped in a biofilm of extracellular glycocalyx that confers increased bacterial resistance against systemic antibiotics, unless the implants are surgically debrided and removed.[31] Local sustained elution of high-dose antibiotics has garnered increasing interest in recent years due to the effectiveness of antibiotic-loaded cement in reducing infection rates.[32] Passive surface modifications,[33] silver coatings,[34] antibiotic-impregnated beads,[35] sponges,[36] bone grafts,[37] and hydrogels[38] have all been used to varying degrees of success, but may not be suitable for arthroplasty due to the risk of cytotoxicity, immunoreactivity, third body wear, or cost concerns.

Vancomycin powder or antibiotic-impregnated calcium sulphate beads have been described in the literature to provide a high local concentration of antibiotics when placed in the soft-tissues of the joint,[9] but have not been shown conclusively to reduce PJI rates. Local antibiotics used in this manner may be useful in eradicating or suppressing soft-tissue infections, however the antibiotics are not placed at the bone-implant surface and are unable to specifically prevent biofilm formation and subsequent antimicrobial proliferation and resistance.

DAC is a hydrogel that can be used alone, or in combination with antibiotics to prevent PJI by multiple mechanisms. The gel acts as a natural barrier and changes the implant surface from hydrophobic to hydrophilic, which has been shown to repel bacterial adhesion and prevent eventual biofilm formation.[39] Hyaluronan also provides an antagonistic effect against hyaluronidase produced by bacteria, and has been shown to have a bacteriostatic effect in vivo and in vitro.[40,41] It is also compatible with many antibiotics and allows for multiple antibiotics to be added, further enhancing its ability to target even multidrug-resistant organisms.

Romanò et al[17] first reported a significant reduction in PJI risk (6% compared with 0.6%; p = 0.003), when antibiotic-loaded DAC was used in a randomized controlled trial of primary and revision, hip and knee arthroplasties. Capuano et al[42] reported, in a multicentre case control study, that single-stage revision with DAC was as effective at reducing reinfection rates as two-stage revision used in a retrospective group of patients (9.1% compared with 13.6%; p > 0.05). De Meo et al[43] showed, in a retrospective matched case control study, that use of DAC for revision THA for aseptic loosening was associated with a significantly reduced risk of PJI (0% compared with 35%; p < 0.001). Franceschini et al[44] reported two failures/reinfections after second-stage revision THA for chronic PJI in a cohort of 28 patients. Zoccali et al[45] similarly demonstrated a statistically significant reduction in post-surgical infection when DAC was used in conjunction with high-risk megaprostheses for both oncological and non-oncological indications (0% compared with 14.0%; p = 0.028). Pellegrini and Legnani[46] reported that the use of DAC for single-stage revision THA PJI in a cohort of ten patients resulted in infection clearance, with complete osseointegration of the implant at an average of 37.2 months' follow-up. In a previous study by Zagra et al,[11] no infections were reported in patients treated with DAC for second-stage revision THA for PJI compared to four in a control group; the difference was, however, not statistically significant due to the small sample size (0% compared with 14.8%; p = 0.110). All previous studies did not report any local or systemic adverse events relating to the use of DAC.

The results of previous studies are concordant with our own, and show a significantly reduced number of complication and infection rates, with negligible side effects. Procedures performed without DAC in all patients, and in second-stage revisions, appeared to be associated with higher rates of infective and non-infective complications. While there may be ongoing concerns regarding inflammatory reaction to the DAC gel and seroma formation, these have not been demonstrated in the known literature and this absence is replicated in our study. The use of DAC gel may also reduce the coefficient of friction in the stem-bone interface, potentially reducing the risk of periprosthetic fractures. There was a statistically significantly higher number of patients with aseptic loosening in the control group in patients treated for PJI. While there have been concerns regarding DAC interfering with osseointegration, other studies have demonstrated the beneficial effects on osseointegration via osteocyte induction, angiogenesis, macrophage polarization, and reducing bacterial adhesion with the use of hydrogel coating on titanium implant surfaces.[47–49] This warrants further study, and could potentially be an added benefit in patients where osseointegration might be a concern.

Our study was limited by a small cohort of patients who underwent high-risk primary and revision THA with DAC, due to delays in obtaining European Conformity certification (CE mark) for the DAC hydrogel from July 2015 to January 2017, the COVID-19 pandemic, and limitation of DAC supply during the study period. An a priori power analysis, however, showed that 79 patients were required in each arm, which made the study adequately powered for statistical analysis. Furthermore, patients were only matched for host type and age. Specific comorbidities such as poorly controlled diabetes, smoking, morbid obesity, and even specific bacteria such as multidrug-resistant strains could contribute to higher complication and reinfection rates. In addition, there was considerable heterogeneity in the primary diagnoses and surgical type performed for the overall cohort. This was mitigated by doing a subgroup analysis focusing only on high-risk second-stage revision THA for PJI patients, which showed statistically significant differences in complication and reinfection rates. While there may be a higher number of DAIR and single-stage revision surgeries performed in the control group, none of the DAIR patients developed a recurrent PJI, and registry results seem to suggest that the re-revision rate following single-stage revision for hip PJI is not inferior to two-stage revisions after the first three months.[50] Another limitation could be the short follow-up and differences in follow-up duration between the DAC and control group. However, a minimum of two years is an accepted duration for excluding reinfections and early major complications including lack of primary stability and osseointegration. Future studies with longer follow-ups would be required to study the effects on late aseptic loosening, although this is not a commonly described complication of antimicrobial coatings.

In conclusion, the use of an antibiotic-impregnated hydrogel coating on cementless implants appears to be associated with decreased complication rates after high-risk primary or revision THA. When used in second-stage revision THA for PJI, it is also associated with reduced risk of reinfection and aseptic loosening.

References

1. **Jin X**, **Gallego Luxan B**, **Hanly M**, **et al**. Estimating incidence rates of periprosthetic joint infection after hip and knee arthroplasty for osteoarthritis using linked registry and administrative health data. *Bone Joint J*. 2022;104-B(9):1060–1066.
2. **Kamath AF**, **Ong KL**, **Lau E**, **et al**. Quantifying the burden of revision total joint arthroplasty for periprosthetic infection. *J Arthroplasty*. 2015; 30(9):1492–1497.
3. **Mühlhofer HML**, **Knebel C**, **Pohlig F**, **et al**. Synovial aspiration and serological testing in two-stage revision arthroplasty for prosthetic joint

infection: evaluation before reconstruction with a mean follow-up of twenty seven months. *Int Orthop*. 2018;42(2):265–271.
4. **Parvizi J**, **Saleh KJ**, **Ragland PS**, **Pour AE**, **Mont MA**. Efficacy of antibiotic-impregnated cement in total hip replacement. *Acta Orthop*. 2008;79(3):335–341.
5. **Schwarz EM**, **Parvizi J**, **Gehrke T**, **et al**. 2018 International Consensus Meeting on Musculoskeletal Infection: research priorities from the General Assembly questions. *J Orthop Res*. 2019;37(5):997–1006.
6. **Hooper GJ**, **Rothwell AG**, **Stringer M**, **Frampton C**. Revision following cemented and uncemented primary total hip replacement: a seven-year analysis from the New Zealand Joint Registry. *J Bone Joint Surg Br*. 2009;91-B(4):451–458.
7. **Donaldson AJ**, **Thomson HE**, **Harper NJ**, **Kenny NW**. Bone cement implantation syndrome. *Br J Anaesth*. 2009;102(1):12–22.
8. **Laffosse JM**. Removal of well-fixed fixed femoral stems. *Orthop Traumatol Surg Res*. 2016;102(1 Suppl):S177–87.
9. **Abosala A**, **Ali M**. The use of calcium sulphate beads in periprosthetic joint infection, a systematic review. *J Bone Jt Infect*. 2020;5(1):43–49.
10. **Gristina AG**, **Naylor P**, **Myrvik Q**. Infections from biomaterials and implants: a race for the surface. *Med Prog Technol*. 1988;14(3–4):205–224.
11. **Zagra L**, **Gallazzi E**, **Romanò D**, **Scarponi S**, **Romanò C**. Two-stage cementless hip revision for peri-prosthetic infection with an antibacterial hydrogel coating: results of a comparative series. *Int Orthop*. 2019;43(1): 111–115.
12. **World Medical Association**. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310(20):2191–2194.
13. **McPherson EJ**, **Woodson C**, **Holtom P**, **Roidis N**, **Shufelt C**, **Patzakis M**. Periprosthetic total hip infection: outcomes using a staging system. *Clin Orthop Relat Res*. 2002;403:8–15.
14. **Boisgard S**, **Descamps S**, **Bouillet B**. Complex primary total hip arthroplasty. *Orthop Traumatol Surg Res*. 2013;99(1 Suppl):S34–42.
15. **Parvizi J**, **Tan TL**, **Goswami K**, **et al**. The 2018 definition of periprosthetic hip and knee infection: an evidence-based and validated criteria. *J Arthroplasty*. 2018;33(5):1309–1314.
16. **Diaz-Ledezma C**, **Higuera CA**, **Parvizi J**. Success after treatment of periprosthetic joint infection: a Delphi-based international multidisciplinary consensus. *Clin Orthop Relat Res*. 2013;471(7):2374–2382.
17. **Romanò CL**, **Malizos K**, **Capuano N**, **et al**. Does an antibiotic-loaded hydrogel coating reduce early post-surgical infection after joint arthroplasty? *J Bone Jt Infect*. 2016;1:34–41.
18. **Harkess JW**, **Crockarell J**. Arthroplasty of the hip. In: Canale ST, Beaty JH, eds. *Campbell's Operative Orthopaedics*. Eleventh ed. Philadelphia, Pennsylvania: Mosby/Elsevier, 2008: 312–481.
19. **Faul F**, **Erdfelder E**, **Lang AG**, **Buchner A**. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175–191.
20. **Brooker AF**, **Bowerman JW**, **Robinson RA**, **Riley LH Jr**. Ectopic ossification following total hip replacement. Incidence and a method of classification. *J Bone Joint Surg Am*. 1973;55-A(8):1629–1632.
21. **Premkumar A**, **Kolin DA**, **Farley KX**, **et al**. Projected economic burden of periprosthetic joint infection of the hip and knee in the United States. *J Arthroplasty*. 2021;36(5):1484–1489.
22. **Goud AL**, **Harlianto NI**, **Ezzafzafi S**, **Veltman ES**, **Bekkers JEJ**, **van der Wal BCH**. Reinfection rates after one- and two-stage revision surgery for hip and knee arthroplasty: a systematic review and meta-analysis. *Arch Orthop Trauma Surg*. 2023;143(2):829–838.
23. **Straub J**, **Staats K**, **Vertesich K**, **Kowalscheck L**, **Windhager R**, **Böhler C**. Two-stage revision for periprosthetic joint infection after hip and knee arthroplasty. *Bone Joint J*. 2024;106-B(4):372–379.
24. **Resl M**, **Becker L**, **Steinbrück A**, **Wu Y**, **Perka C**. Re-revision and mortality rate following revision total hip arthroplasty for infection. *Bone Joint J*. 2024;106-B(6):565–572.
25. **Petrie MJ**, **Panchani S**, **Al-Einzy M**, **Partridge D**, **Harrison TP**, **Stockley I**. Systemic antibiotics are not required for successful two-stage revision hip arthroplasty. *Bone Joint J*. 2023;105-B(5):511–517.
26. **Yoon B-H**, **Ha Y-C**, **Lee Y-K**, **Koo K-H**. Postoperative deep infection after cemented versus cementless total hip arthroplasty: a meta-analysis. *J Arthroplasty*. 2015;30(10):1823–1827.
27. **Davis N**, **Curry A**, **Gambhir AK**, **et al**. Intraoperative bacterial contamination in operations for joint replacement. *J Bone Joint Surg Br*. 1999;81-B(5):886–889.
28. **Abdel-Kader KF**, **Allcock S**, **Walker DI**, **Chaudhry SB**. Boneloc bone-cement: experience in hip arthroplasty during a 3-year period. *J Arthroplasty*. 2001;16(7):811–819.
29. **Lindberg-Larsen M**, **Petersen PB**, **Jørgensen CC**, **Overgaard S**, **Kehlet H**, **Lundbeck Foundation Center for Fast-track Hip and Knee Arthroplasty Collaborating Group**. Postoperative 30-day complications after cemented/hybrid versus cementless total hip arthroplasty in osteoarthritis patients > 70 years. *Acta Orthop*. 2020;91(3):286–292.
30. **McDonald DJ**, **Fitzgerald RH Jr**, **Ilstrup DM**. Two-stage reconstruction of a total hip arthroplasty because of infection. *J Bone Joint Surg Am*. 1989;71-A(6):828–834.
31. **Foster TJ**, **Geoghegan JA**, **Ganesh VK**, **Höök M**. Adhesion, invasion and evasion: the many functions of the surface proteins of Staphylococcus aureus. *Nat Rev Microbiol*. 2014;12(1):49–62.
32. **Leong JW**, **Cook MJ**, **O'Neill TW**, **Board TN**. Is the use of antibiotic-loaded bone cement associated with a lower risk of revision after primary total hip arthroplasty? *Bone Joint J*. 2020;102-B(8):997–1002.
33. **Braem A**, **Van Mellaert L**, **Mattheys T**, **et al**. Staphylococcal biofilm growth on smooth and porous titanium coatings for biomedical applications. *J Biomed Mater Res A*. 2014;102(1):215–224.
34. **Parry MC**, **Laitinen MK**, **Albergo JI**, **et al**. Silver-coated (Agluna®) tumour prostheses can be a protective factor against infection in high risk failure patients. *Eur J Surg Oncol*. 2019;45(4):704–710.
35. **Tarity TD**, **Xiang W**, **Jones CW**, **et al**. Do antibiotic-loaded calcium sulfate beads improve outcomes after debridement, antibiotics, and implant retention? A matched cohort study. *Arthroplast Today*. 2022;14: 90–95.
36. **Wouthuyzen-Bakker M**, **Löwik CAM**, **Knobben BAS**, **et al**. Use of gentamicin-impregnated beads or sponges in the treatment of early acute periprosthetic joint infection: a propensity score analysis. *J Antimicrob Chemother*. 2018;73(12):3454–3459.
37. **Winkler H**, **Stoiber A**, **Kaudela K**, **Winter F**, **Menschik F**. One stage uncemented revision of infected total hip replacement using cancellous allograft bone impregnated with antibiotics. *J Bone Joint Surg Br*. 2008;90-B(12):1580–1584.
38. **Sille IE**, **Pissinis DE**, **Fagali NS**, **Ghilini F**, **Urrutia MN**, **Schilardi PL**. Antimicrobial-loaded polyacrylamide hydrogels supported on titanium as reservoir for local drug delivery. *Pathogens*. 2023;12(2):202.
39. **Harris LG**, **Richards RG**. Staphylococci and implant surfaces: a review. *Injury*. 2006;37 Suppl 2:S3–14.
40. **Pirnazar P**, **Wolinsky L**, **Nachnani S**, **Haake S**, **Pilloni A**, **Bernard GW**. Bacteriostatic effects of hyaluronic acid. *J Periodontol*. 1999;70(4):370–374.
41. **Carlson GA**, **Dragoo JL**, **Samimi B**, **et al**. Bacteriostatic properties of biomatrices against common orthopaedic pathogens. *Biochem Biophys Res Commun*. 2004;321(2):472–478.
42. **Capuano N**, **Logoluso N**, **Gallazzi E**, **Drago L**, **Romanò CL**. One-stage exchange with antibacterial hydrogel coated implants provides similar results to two-stage revision, without the coating, for the treatment of peri-prosthetic infection. *Knee Surg Sports Traumatol Arthrosc*. 2018; 26(11):3362–3367.
43. **De Meo D**, **Calogero V**, **Are L**, **Cavallo AU**, **Persiani P**, **Villani C**. Antibiotic-loaded hydrogel coating to reduce early postsurgical infections in aseptic hip revision surgery: a retrospective, matched case-control study. *Microorganisms*. 2020;8(4):571.
44. **Franceschini M**, **Sandiford NA**, **Cerbone V**, **Araujo LCT**, **Kendoff D**. Defensive antibacterial coating in revision total hip arthroplasty: new concept and early experience. *Hip Int*. 2020;30(1_suppl):7–11.
45. **Zoccali C**, **Scoccianti G**, **Biagini R**, **Daolio PA**, **Giardina FL**, **Campanacci DA**. Antibacterial hydrogel coating in joint mega-prosthesis: results of a comparative series. *Eur J Orthop Surg Traumatol*. 2021;31(8): 1647–1655.
46. **Pellegrini A**, **Legnani C**. High rate of infection eradication following cementless one-stage revision hip arthroplasty with an antibacterial hydrogel coating. *Int J Artif Organs*. 2022;45(1):113–117.
47. **Chen H**, **Feng R**, **Xia T**, **et al**. Progress in surface modification of titanium implants by hydrogel coatings. *Gels*. 2023;9(5):423.
48. **Liu Z**, **Xu Z**, **Wang X**, **et al**. Construction and osteogenic effects of 3D-printed porous titanium alloy loaded with VEGF/BMP-2 shell-core microspheres in a sustained-release system. *Front Bioeng Biotechnol*. 2022;10:1028278.
49. **Liu H**, **Li W**, **Liu C**, **et al**. Incorporating simvastatin/poloxamer 407 hydrogel into 3D-printed porous Ti_6Al_4V scaffolds for the promotion of

angiogenesis, osseointegration and bone ingrowth. *Biofabrication*. 2016;8(4):045012.

50. **Lenguerrand E**, **Whitehouse MR**, **Beswick AD**, **et al**. Mortality and re-revision following single-stage and two-stage revision surgery for the management of infected primary hip arthroplasty in England and Wales. *Bone Joint Res*. 2023;12(5):321–330.

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The study was conducted in accordance with the principles of the Helsinki Declaration and obtained approval from the local ethics board. All patients gave informed consent for data collection and analysis.

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