■ THE INTERNATIONAL HIP SOCIETY

Intra-articular antibiotics

A DIRECT APPROACH TO THE TREATMENT OF INFECTED CEMENTLESS TOTAL HIP ARTHROPLASTY

F-J. Vandeputte,
M. Gevers,
H. Welters,
K. Corten

From Ziekenhuis Oost-Limburg, Genk, Belgium

Aims

The use of intra-articular antibiotics in the treatment of periprosthetic joint infection (PJI) can achieve a concentration which is sufficient to eradicate a biofilm. This may mitigate the need for removal of infected but well-fixed cementless components of a total hip arthroplasty (THA). However, the use of percutaneous catheters might lead to multiresistance or persistent multiorganism infections. The aim of this study was to report the results of a series in which an intra-articular antibiotic infusion was added to a single-stage revision for infected cementless THAs.

Methods

A total of 18 patients underwent 18 single-stage revision THAs which were performed for acute (n = 9) or chronic (n = 9) PJI, following a primary (n = 12) or revision (n = 6) cementless THA. After an extensive debridement, modular components were replaced, but all well-fixed components were retained. Two Hickmann catheters were introduced into the joint space, through which intra-articular antibiotics were introduced for two weeks. Intravenous antibiotics were also administered during this time, followed by oral antibiotics until three months after surgery.

Results

At a mean follow-up of 5.4 years (3.3 to 7.19), all patients had a normal ESR and white blood cell count. The CRP remained slightly elevated in three patients, although they were pain-free and showed no signs of infection. No patient developed antibiotic-related renal or systemic dysfunction postoperatively.

Conclusion

We found that for the treatment of an infected cementless THA, retention of well-fixed components was feasible, with the addition of intra-articular antibiotics to a standard single-stage regime. None of the 18 patients had persistent infection or catheter-induced drug resistance, at a mean follow-up of 5.4 years.

Cite this article: *Bone Joint J* 2025;107-B(6 Supple B):3–8.

Introduction

Periprosthetic joint infection (PJI) can be a devastating complication of total hip arthroplasty (THA), with an incidence of between 0.5% and 2% in primary THA and 15% of revision THAs.[1,2] The most efficient treatment of a PJI remains controversial.[3,4] In general, three distinct strategies can be used: two-stage revision, single-stage revision (SSR), and debridement, antibiotics, and implant retention (DAIR).[1] Of these, a two-stage revision using an antibiotic-loaded cement spacer remains the gold standard.[5] However, the use of a cement spacer can require the removal of firmly fixed components with a risk of complications including dislocation, bone loss, fracture, failure to reimplant, recurrent infection, and mortality.[6] Single-stage revision is associated with lower morbidity, mortality, and costs.[7-11] Rates of recurrent infection which are comparable to those of a two-stage revision have been reported in several studies, and single-stage revisions are increasingly being used in these patients.[8,12-14] The DAIR procedure has the benefit of the retention of the components, but may be associated with a suboptimal eradication of the bacterial load and the biofilm, although it may be successful in patients with an acute infection.[15–17]

Correspondence should be sent to F-J. Vandeputte; email: frandeputte@gmail.com

doi:10.1302/0301-620X.107B6.BJJ-2024-0853.R1 $2.00

Bone Joint J 2025;107-B(6 Supple B):3–8.

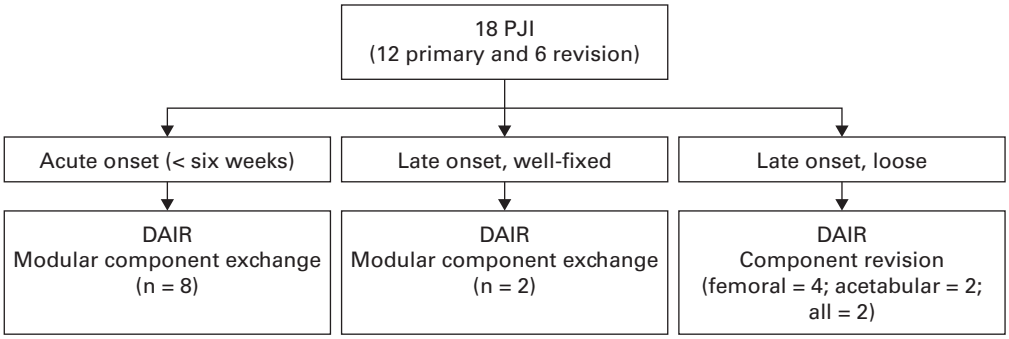

Fig. 1

Overview of the treatment of the patients. DAIR, debridement, antibiotics, and implant retention; PJI, periprosthetic joint infection.

The biofilm (glycocalyx) is considered to be the most critical factor influencing the treatment of PJI because of its microenvironment on the surface of components acting as a barrier to the penetration of antibiotics.[1] For certain bacterial species, the minimum biofilm eradication concentration (MBEC) of an antibiotic can be between 100 and 1,000 times higher than the minimal inhibitory concentration (MIC).[18,19] The intravenous or oral administration of antibiotics cannot achieve these high concentrations without causing systemic toxicity.[20,21] Antibiotic-loaded cement spacers can reach the MBEC for only between 24 and 48 hours.[22,23] The repeated injection of high doses of antibiotics directly into the joint space has been shown to reach the MBEC for a prolonged period of time.[20,21,24,25] This form of treatment may be used to treat methicillin-resistant *Staphylococcus aureus*, methicillin-resistant *Staphylococcus epidermis*, and polybacterial PJI.[26,27]

The technique of single-stage revision with the addition of intra-articular antibiotics was first described for infected total knee arthroplasty (TKA),[24,26–29] and subsequently for infected THA.[30–33] Retention of well-fixed cementless components is reported in only one series including nine patients who underwent revision THA for PJI.[33] The intra-articular infusion of antibiotics was continued for six weeks postoperatively in the studies in which this technique has been reported.[26–30,32–35]

The aim of this study was to describe a series of patients with PJI following cementless THA, successfully treated using single-stage revision with retention of the implants and the intra-articular infusion of antibiotics for two weeks.

Methods

This single-centre retrospective study involved a series of PJIs of cementless THA presenting between May 2016 and March 2021, with a minimum follow-up of three years. The study had ethical approval (CTU no. Z2021073), and the patients gave informed consent.

The diagnosis of PJI was based on the algorithm described by Parvizi et al[36] and Shohat et al[37] in 2018 and 2019, respectively. An aspiration of the joint was performed preoperatively. An acute PJI was defined as one presenting < six weeks postoperatively. [38]

A total of 21 patients (21 THAs) were initially included. Exclusion criteria were those with a two-stage revision (n = 1), a total femoral prosthesis (n = 1), or > two previous revision THAs (n = 1). The definitive study therefore included 18 patients (18 THAs) who underwent a single-stage revision with additional intra-articular antibiotic infusion; nine had an acute-onset and nine had a late-onset (Figure 1). There were five female and 13 male patients. Their mean age was 61 years (SD 15) and the mean follow-up was 64.2 months (SD 16.9; 36 to 89). The mean BMI was 30.5 kg/m^2 (SD 5.5). Ten patients, seven with acute-onset and three with late-onset PJI, were treated with a DAIR procedure and only modular (liner and head) component exchange. In four patients, all late-onset PJI, the acetabular component was retained. The femoral component was retained in two patients. All the components were exchanged in two patients. A summary of the procedures and the associated antibiotic treatment is shown in Table I.

All operations were undertaken using the direct anterior approach.[39] If deemed necessary, the approach was extended proximally or distally.[40,41] Following capsulotomy, at least four tissue samples were obtained for microbiological examination. An extensive debridement of the joint space and surrounding infected soft-tissues was undertaken. In patients with bony ingrowth on preoperative radiological and stable macroscopic fixation during surgery, a DAIR procedure was undertaken. If either the acetabular and/or femoral component showed signs of loosening, they were removed. The joint space, retained components, and bone were thoroughly irrigated with six litres of saline (NaCl 0.9%) before closing the wound and starting a 'clean phase' with renewed draping, new instruments, and another irrigation with three litres of saline. New cementless components were introduced and the hip was tested for stability. Two double lumen Hickmann catheters were introduced percutaneously in a retrograde fashion, tunnelled through the muscle envelope over a distance of 65 cm, with the tip projecting intra-articularly around the neck of the femoral component, as described by Whiteside and Roy.[33] One or two vacuum drains were also placed intra-articularly. A sterile bandage was applied to the wound and around the Hickmann catheters.

Intravenous antibiotic treatment was administered from the start of the 'clean phase', based on the sensitivities of the preoperative aspirate. In patients with a negative preoperative culture, vancomycin was used as the antibiotic of choice. Multidisciplinary follow-up included adjustment of the intravenous

Table I. A summary of the patients, the treatment protocol and evolution of inflammatory blood parameters (normal values: CRP ≤ 5 mg/dl, ESR ≤15 mm/hr, and WBC 6 to 11 × 10^9/l).

Case	Revision procedure	Onset PJI	Bacterial culture	Antibiotics			eGFR preop	Postop wound leakage	Early removal drain	Postop drainage seroma	eGFR at discharge	CRP				Final follow-up		Days in hospital
				IA	IV	Oral						2 wks	6 wks	6 mths	Final follow-up	WBC	ESR	
1	Femoral/ acetabular component	Late-onset	*Staphylococcus lugdunensis*	Vancomycin	Flucloxacillin	Rifampicin Clindamycin	72	-	-	-	73	5.9	6.5	3.7	1.3	5.5	14	19
2	DAIR	Acute	*Enterobacter aerogenes Klebsiella pneumoniae Pseudomonas aeruginosa Enterococcus faecalis*	Vancomycin	Flucloxacillin Clindamycin Gentamycine	Amoxicillin Ciprofloxacin	90	-	-	-	87	47	43.8	8.4	12.3	6.9	12	23
3	DAIR	Late-onset	*Streptococcus agalactiae*	Vancomycin	Penicillin	Clindamycin	90	-	-	-	90	17	0.9	0.6	0.7	5.8	6	33
4	Acetabular component	Late-onset	*Propionibacterium avidum*	Clindamycin	Clindamycin	Clindamycin	90	-	-	-	90	5.9	5.5	4.7	< 0.6	4.8	8	22
5	Acetabular component	Acute	*Propionibacterium avidum*	Clindamycin	Clindamycin	Clindamycin	90	-	-	-	90	2.7	1.4	3.0	0.7	6.7	8	14
6	Femoral/ acetabular component	Acute	*Corynebacterium* species *Actinomyces odontolyticus Staphylococcus epidermidis*	Flucloxacillin	Flucloxacillin	Flucloxacillin	89	-	-	-	79	42.3	9.0	8.0	10.4	9.1	12	22
7	Femoral component	Late-onset	*Staphylococcus capitis*	Clindamycin	Clindamycin	Clindamycin	90	-	-	-	81	1.7	2.7	1.4	1.1	7.8	10	14
8	DAIR	Late-onset	*Stapylococcus capitis*	Clindamycin	Clindamycin	Clindamycin	90	-	-	-	90	6.3	12	4.0	0.8	6.6	5	15
9	Femoral component	Late-onset	*Propionibacterium avidum*	Clindamycin	Clindamycin	Clindamycin	90	-	-	-	90	5.5	6.5	3.7	2.5	6.2	12	16
10	DAIR	Acute	*Stapylococcus epidermidis*	Vancomycin	Vancomycin	Rifampicin Doxycyclin	88	-	-	-	89	7.1	5.0	3.6	1.1	5.6	4	23
11	DAIR	Late-onset	*Staphylococcus lugdunensis*	Vancomycin	Vancomycin Ciprofloxacin	Ciprofloxacin	52	+	+	+	84	49.7	3.6	1.7	< 5.0	8.7	9	31
12	DAIR	Acute	*Staphylococcus aureus*	Vancomycin	Flucloxacillin Rifampicin	Flucloxacillin Rifampicin	57,2	-	-	-	62	54.9	23.5	1.9	0.6	4.3	4	21
13	DAIR	Acute	*Staphylococcus aureus*	Vancomycin	Flucloxacillin Rifampicin	Flucloxacillin Rifampicin	67	-	-	-	68	37	25.0	7.0	6.4	7.2	11	24
14	DAIR	Acute	*Escherichia coli Enterobacter cloacae*	Vancomycin	Ciprofloxacin	Ciprofloxacin	51	+	+	+	55	14.5	5.4	5.4	5.0	5.8	14	17
15	Femoral component	Late-onset	*Staphylococcus lugdunensis*	Vancomycin	Flucloxacillin	Rifampicin	90	+	+	-	90	8.5	4.9	1.3	1.2	8.1	15	14
16	Femoral component	Late-onset	*Stapylococcus epidermidis*	Vancomycin	Vancomycin	Rifampicin	88	+	-	-	90	34	4.7	2.2	3.9	5.4	7	21
17	DAIR	Acute	*Escherichia coli*	Vancomycin	Rifampicin Ciprofloxacin	Ciprofloxacin	90	+	-	-	88	57.8	1.2	0.8	1.	6.2	14	16
18	DAIR	Acute	*Staphylococcus epidermidis Streptococcus dysgalactiae*	Vancomycin	Amoxicilline Amukacin	Rifampicin	86	-	-	-	86	22.9	12.5	51.3	1.9	3.5	14	21

DAIR, debridement, antibiotics, and implant retention; eGFR, estimated glomerular filtration rate; IA, intraarticular; IV, intravenous; PJI, periprosthetic joint infection.

antibiotic treatment, as required. In-hospital treatment continued for two weeks, including mobilization fully weightbearing. The catheters and drains were then removed. Thrombophylaxis with low-molecular-weight-heparin continued for six weeks. The patients were discharged when there was no evidence of wound leakage. Oral antibiotics were continued until three months after surgery. The patients were reviewed clinically and biochemically at six and 12 weeks, and at six and 12 months, postoperatively.

The additional intra-articular antibiotics, following a protocol, were administered twice a day. First, intra-articular fluid was aspirated through one catheter. Second, another lumen of the same catheter was flushed with 2.5 ml of heparin (dosage 100 IU/ml) before and after the antibiotics were introduced. Antibiotics were added to 10 ml saline in the following dose: vancomycin 1,000 mg, clindamycin 600 mg, and flucloxacillin 2,000 mg. In the next cycle, the other catheter with two lumens was used. Before the intra-articular administration of antibiotics, both vacuum drains (continuous suction) were closed, and opened again two hours later.

The clinical, surgical, biochemical, and electronic hospital records were screened. Clinical signs of infection such as wound drainage, local erythema or swelling, or systemic symptoms (fever, chills, and malaise) were evaluated.[42] Inflammatory parameters (CRP, white-blood cell count (WBC), ESR)) and kidney function (glomerular filtration ratio (GFR) and creatinine level) were recorded. The biochemical evaluation while the patients were in hospital included two to three blood samples being taken each week. Samples were also collected at six weeks, three months, and one year postoperatively. Radiological signs of loosening were evaluated at a minimum of one-year follow-up and at the final follow-up.[43]

Statistical analysis. Analyses were performed using SPSS v. 27 (IBM, USA). Continuous variables were analyzed using descriptive statistics. Values were expressed using means and SD. We used a paired *t*-test for normal distributed data. A p-value < 0.05 was considered significant.

Results

The clinical and biochemical results are shown in Table I. Immediately postoperatively, all patients had increased inflammatory blood parameters due to the extensive surgery. At the end of the intra-articular antibiotic treatment, two weeks after surgery, all patients had normal WBC (6 to 11 × 10^9/l) and vastly improved CRP (normal < 5 mg/dl) and ESR (normal < 15 mm/hr) levels. The mean CRPs and ESRs decreased to 23.26 mg/dl (2.7 to 57.8) and 49.47 mm/hr (17 to 115), respectively. Both further decreased.[44] At the final follow-up at a mean of 64 months (36 to 86), all patients had normal ESR and WBC levels.[36] The CRP remained slightly elevated (6.4 to 12.3 mg/l) in three patients, although they were pain-free and showed no signs of infection. None of the patients developed a fistula.

Renal function was closely monitored during hospitalization. The mean GFR was 81.12 ml/min (SD 14.35) preoperatively and 82.33 ml/min (SD 10.82; p = 0.555) at the time of discharge. The mean creatinine levels also remained unchanged (0.88 mg/dl (SD 0.22) vs 0.85 mg/dl (SD 0.24p = 0.288). In patients treated with vancomycin, the mean preoperative GFR (76.77 ml/min (SD 16.00)) and creatinine (0.95 mg/dl (SD 0.193)) did not change significantly at 80.17 ml/min (SD 12.39) and 0.87 mg/dl (SD 0.193), respectively (p = 0.230 and p = 0.283, respectively, both paired *t*-test). The patients stayed in hospital after surgery for a mean of 20 days (SD 5; 14 to 33) No patient had abnormal renal function at the time of discharge (Table I). There were no radiological signs of loosening or subsidence at a mean follow-up of 27 months (16 to 59).

There were some minor adverse events relating to the intra-articular infusion of antibiotics. All patients complained of mild pressure or tenderness in the groin during or immediately after the infusion. Drains, which were occluded, were removed in three patients; two developed a seroma which required drainage. There was no occlusion of the Hickmann catheters. Finally, after removal of the suction drains and Hickmann catheters, the wounds drained for several days. Five patients experienced prolonged serosanguineous leakage from the surgical wound, but drainage was required in only two of them.

Discussion

At the final follow-up in this study, all 18 patients had normal ESRs and WBC levels.[36,42] Three patients had a slightly elevated CRP level (> 5 mg/dl). The optimal threshold for the CRP in the diagnosis of a chronic PJI after THA is 13.5 mg/l. Thus, no patient had a suspiciously elevated CRP level at this time.[45] The presence of one minor criterion is also not sufficient to diagnose PJI.[36,42] Thus, in the absence of any clinical suspicion, we do not consider this finding reflected residual infection.

We found that the retention of well-fixed components was feasible in the surgical management of an infected cementless THA, with the addition of intra-articular antibiotics to a routine single-stage revision without causing systemic impairment, catheter occlusion, or catheter-induced further infection. However, there were complications as all patients had discomfort in the groin during intra-articular infusion, two required drainage of a seroma, and five had persistent wound drainage.

Whiteside and Roy[33] reported comparable results in nine patients with an infected cementless THA, which was treated with DAIR and remained free of signs of infection at a mean follow-up of 74 months (62 to 121). However, intra-articular antibiotic infusion was continued for six weeks in total and during this time the intra-articular dose of antibiotic was gradually increased. The patients also had some concomitant intravenous treatment during the first days until target serum levels were achieved; it was then discontinued. A similar outcome was achieved by our protocol with only two weeks of combined intra-articular and intravenous antibiotic administration. Oral antibiotics were subsequently continued because the Oral versus Intravenous Antibiotics (OVIVA) trial clearly demonstrated that oral antibiotic treatment was not inferior to intravenous antibiotic therapy when used during the first six weeks for complex orthopaedic infections.[46] The use of our protocol reduced the need for hospitalization, and might improve patient satisfaction and cost-effectiveness in these patients. To our knowledge, this is only the second series investigating additional intra-articular antibiotic infusion in the treatment of an infected cementless THA, and it had twice the number of cases.

Ji et al[32] reported a series of 104 infected THAs treated with combined intra-articular and intravenous antibiotic infusion for a mean of 16 days postoperatively, with oral antibiotics for a further mean of 12 weeks. Infection control was achieved for 98 patients (94%). However, the authors consistently performed revision of all components and did not specify whether the initial implants were cementless or not. While they discussed the beneficial effects of intra-articular antibiotics in single-stage revision with full revision of components, the harm of removing well-fixed components may be avoided if intra-articular antibiotics achieve MBEC.[32] We were able to retain well-fixed components and achieve infection control in all our patients.

Vancomycin was the most frequently used antibiotic for both intra-articular and intravenous treatment. Its potential nephrotoxic effect is well known.[47] We, however, found no significant decrease in renal function in any patient, and we believe that the combined administration of intra-articular and intravenous antibiotics under these circumstances is safe. Besides vancomycin, clindamycin and (in one patient) flucloxacillin were infused directly in the joint, suggesting that intra-articular antibiotic infusion does not need to be limited to glycopeptides. Although it is well known that glycopeptides penetrate the glycocalyx best, antibiotics to which the patients' organism is sensitive are preferred.

This study had limitations. First, it was a small case series. However, previous studies describing additional intra-articular antibiotics were also case series with a similar number of patients. Studies with larger sample-sizes are often characterized by heterogeneity. Second, we did not examine the aspirate from the Hickmann catheters. However, there is already evidence that a MBEC may be achieved by the intra-articular delivery of antibiotics.[34] Nevertheless, an extensive debridement of the joint space and surrounding soft-tissues is essential. We also only included THAs with a bone-implant interface, and our findings cannot be generalized to cemented THAs. Lastly, the eradication of PJI was based on clinical, biochemical, and radiological findings. Additional joint aspiration with fluid culture and alpha-defensin determination would require extensive further invasive investigations and was not collected. However, these results could encourage a randomized control trial to confirm the findings. Larger studies could assess this technique better and allow prospective comparisons to be made with more traditional single- and two-stage revision techniques for the treatment of infected THAs. These will probably require multi-institutional approaches.

In summary, the successful treatment of an infected cementless THA, with retention of well-fixed components, seems feasible using a single-stage revision with the addition of intra-articular antibiotic infusion. None of the 18 patients had persistent infection or catheter-induced drug resistance at a mean follow-up of 5.4 years.

Take home message

- Succesful treatment of an infected cementless total hip arthroplasty, with retention of well-fixed components, seems feasible using a single-stage revision with the addition of an intra-articular antibiotic infusion.

References

1. **Mian HM**, **Lyons JG**, **Perrin J**, **Froehle AW**, **Krishnamurthy AB**. A review of current practices in periprosthetic joint infection debridement and revision arthroplasty. *Arthropl*. 2022;4(1):31.
2. **Perfetti DC**, **Boylan MR**, **Naziri Q**, **Paulino CB**, **Kurtz SM**, **Mont MA**. Have periprosthetic hip infection rates plateaued? *J Arthroplasty*. 2017;32(7):2244–2247.
3. **Leonard HAC**, **Liddle AD**, **Burke O**, **Murray DW**, **Pandit H**. Single- or two-stage revision for infected total hip arthroplasty? A systematic review of the literature. *Clin Orthop Relat Res*. 2014;472(3):1036–1042.
4. **Negus JJ**, **Gifford PB**, **Haddad FS**. Single-stage revision arthroplasty for infection-an underutilized treatment strategy. *J Arthroplasty*. 2017;32(7):2051–2055.
5. **Lazic I**, **Scheele C**, **Pohlig F**, **von Eisenhart-Rothe R**, **Suren C**. Treatment options in PJI - is two-stage still gold standard? *J Orthop*. 2021;23:180–184.
6. **Kozaily E**, **Tan TL**, **Yacovelli S**, **et al**. Interim spacer exchange for treatment of periprosthetic joint infection: almost half the patients subsequently fail. *J Arthroplasty*. 2022;37(1):150–155.
7. **Ji B**, **Wahafu T**, **Li G**, **et al**. Single-stage treatment of chronically infected total hip arthroplasty with cementless reconstruction. *Bone Joint J*. 2019;101-B(4):396–402.
8. **George DA**, **Logoluso N**, **Castellini G**, **et al**. Does cemented or cementless single-stage exchange arthroplasty of chronic periprosthetic hip infections provide similar infection rates to a two-stage? A systematic review. *BMC Infect Dis*. 2016;16(1):553.
9. **Hansen E**, **Tetreault M**, **Zmistowski B**, **et al**. Outcome of one-stage cementless exchange for acute postoperative periprosthetic hip infection. *Clin Orthop Relat Res*. 2013;471(10):3214–3222.
10. **Lum ZC**, **Holland CT**, **Meehan JP**. Systematic review of single stage revision for prosthetic joint infection. *World J Orthop*. 2020;11(12):559–572.
11. **Ahmed SS**, **Begum F**, **Kayani B**, **Haddad FS**. Risk factors, diagnosis and management of prosthetic joint infection after total hip arthroplasty. *Expert Rev Med Devices*. 2019;16(12):1063–1070.
12. **Yaghmour KM**, **Chisari E**, **Khan WS**. Single-stage revision surgery in infected total knee arthroplasty: a PRISMA systematic review. *J Clin Med*. 2019;8(2):174.
13. **Razii N**, **Clutton JM**, **Kakar R**, **Morgan-Jones R**. Single-stage revision for the infected total knee arthroplasty: the Cardiff experience. *Bone Jt Open*. 2021;2(5):305–313.
14. **Maale GE**, **Eager JJ**, **Srinivasaraghavan A**, **Mohammadi DK**, **Kennard N**. The evolution from the two stage to the one stage procedure for biofilm based periprosthetic joint infections (PJI). *Biofilm*. 2020;2:100033.
15. **Siqueira MBP**, **Saleh A**, **Klika AK**, **et al**. Chronic suppression of periprosthetic joint infections with oral antibiotics increases infection-free survivorship. *J Bone Joint Surg Am*. 2015;97-A(15):1220–1232.
16. **Tsang S-TJ**, **Ting J**, **Simpson AHRW**, **Gaston P**. Outcomes following debridement, antibiotics and implant retention in the management of periprosthetic infections of the hip: a review of cohort studies. *Bone Joint J*. 2017;99-B(11):1458–1466.
17. **Longo UG**, **De Salvatore S**, **Bandini B**, **et al**. Debridement, antibiotics, and implant retention (DAIR) for the early prosthetic joint infection of total knee and hip arthroplasties: a systematic review. *J ISAKOS*. 2024;9(1):62–70.
18. **Høiby N**, **Bjarnsholt T**, **Givskov M**, **Molin S**, **Ciofu O**. Antibiotic resistance of bacterial biofilms. *Int J Antimicrob Agents*. 2010;35(4):322–332.
19. **Tuon FF**, **Suss PH**, **Telles JP**, **Dantas LR**, **Borges NH**, **Ribeiro VST**. Antimicrobial treatment of *Staphylococcus aureus* biofilms. *Antibiotics (Basel)*. 2023;12(1):87.
20. **Wei J**, **Tong K**, **Wang H**, **Wen Y**, **Chen L**. Intra-articular versus systemic vancomycin for the treatment of periprosthetic joint infection after debridement and spacer implantation in a rat model. *Bone Joint Res*. 2022;11(6):371–385.
21. **He J**, **Wang J**, **Cao L**, **et al**. Determination of vancomycin and meropenem in serum and synovial fluid of patients with prosthetic joint infections using UPLC-MS/MS. *J Mass Spectrom*. 2024;59(6):e5041.
22. **Anagnostakos K**, **Meyer C**. Antibiotic elution from hip and knee acrylic bone cement spacers: a systematic review. *Biomed Res Int*. 2017;2017:4657874.
23. **Kelm J**, **Regitz T**, **Schmitt E**, **Jung W**, **Anagnostakos K**. In vivo and in vitro studies of antibiotic release from and bacterial growth inhibition by antibiotic-impregnated polymethylmethacrylate hip spacers. *Antimicrob Agents Chemother*. 2006;50(1):332–335.
24. **Whiteside LA**, **Roy ME**, **Nayfeh TA**, **Surgeon O**. Intra-articular infusion a direct approach to treatment of infected total. *Knee Arthroplasty*. 2016;98(1).
25. **Zou C**, **Guo W**, **Mu W**, **et al**. Synovial vancomycin and meropenem concentrations in periprosthetic joint infection treated by single-stage revision combined with intra-articular infusion. *Bone Joint Res*. 2024;13(10):535–545.
26. **Whiteside LA**, **Peppers M**, **Nayfeh TA**, **Roy ME**. Methicillin-resistant Staphylococcus aureus in TKA treated with revision and direct intra-articular antibiotic infusion. *Clin Orthop Relat Res*. 2011;469(1):26–33.

27. **Whiteside LA**, **Nayfeh TA**, **LaZear R**, **Roy ME**. Reinfected revised TKA resolves with an aggressive protocol and antibiotic infusion. *Clin Orthop Relat Res*. 2012;470(1):236–243.
28. **Chaiyakit P**, **Meknavin S**, **Hongku N**, **Onklin I**. Debridement, antibiotics, and implant retention combined with direct intra-articular antibiotic infusion in patients with acute hematogenous periprosthetic joint infection of the knee. *BMC Musculoskelet Disord*. 2021;22(1):557.
29. **Roy ME**, **Peppers MP**, **Whiteside LA**, **Lazear RM**. Vancomycin concentration in synovial fluid: direct injection into the knee vs. intravenous infusion. *J Arthroplasty*. 2014;29(3):564–568.
30. **Antony SJ**, **Westbrook RS**, **Jackson JS**, **Heydemann JS**, **Nelson JL**. Efficacy of single-stage revision with aggressive debridement using intra-articular antibiotics in the treatment of infected joint prosthesis. *Infect Dis*. 2015;8:17–23.
31. **Ji B**, **Li G**, **Zhang X**, **et al**. Effective single-stage revision using intra-articular antibiotic infusion after multiple failed surgery for periprosthetic joint infection: a mean seven years' follow-up. *Bone Joint J*. 2022;104-B(7):867–874.
32. **Ji B**, **Li G**, **Zhang X**, **Wang Y**, **Mu W**, **Cao L**. Effective treatment of single-stage revision using intra-articular antibiotic infusion for culture-negative prosthetic joint infection. *Bone Joint J*. 2020;102-B(3):336–344.
33. **Whiteside LA**, **Roy ME**. One-stage revision with catheter infusion of intraarticular antibiotics successfully treats infected THA. *Clin Orthop Relat Res*. 2017;475(2):419–429.
34. **Whiteside LA**, **Roy ME**, **Nayfeh TA**. Intra-articular infusion: a direct approach to treatment of infected total knee arthroplasty. *Bone Joint J*. 2016;98-B(1 Suppl A):31–36.
35. **Ji B**, **Li G**, **Zhang X**, **et al**. Effective single-stage revision using intra-articular antibiotic infusion after multiple failed surgery for periprosthetic joint infection. *Bone Joint J*. 2022;104-B(7):867–874.
36. **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.
37. **Shohat N**, **Tan TL**, **Della Valle CJ**, **et al**. Development and validation of an evidence-based algorithm for diagnosing periprosthetic joint infection. *J Arthroplasty*. 2019;34(11):2730–2736.
38. **Christopher ZK**, **McQuivey KS**, **Deckey DG**, **Haglin J**, **Spangehl MJ**, **Bingham JS**. Acute or chronic periprosthetic joint infection? Using the ESR/CRP ratio to aid in determining the acuity of periprosthetic joint infections. *J Bone Jt Infect*. 2021;6(6):229–234.
39. **Corten K**, **Holzapfel BM**. Direct anterior approach for total hip arthroplasty using the "bikini incision." *Oper Orthop Traumatol*. 2021;33(4):318–330.
40. **Ghijselings SGM**, **Driesen R**, **Simon J-P**, **Corten K**. Distal extension of the anterior approach to the hip using the femoral interbundle technique: surgical technique and case series. *J Arthroplasty*. 2017;32(7):2186–2190.
41. **Molenaers B**, **Driesen R**, **Molenaers G**, **Corten K**. The direct anterior approach for complex primary total hip arthroplasty: the extensile acetabular approach on a regular operating room table. *J Arthroplasty*. 2017;32(5):1553–1559.
42. **Kim SJ**, **Cho YJ**. Current guideline for diagnosis of periprosthetic joint infection: a review article. *Hip Pelvis*. 2021;33(1):11–17.
43. **Mushtaq N**, **To K**, **Gooding C**, **Khan W**. Radiological imaging evaluation of the failing total hip replacement. *Front Surg*. 2019;6:35.
44. **Litao MKS**, **Kamat D**. Erythrocyte sedimentation rate and C-reactive protein: how best to use them in clinical practice. *Pediatr Ann*. 2014;43(10):417–420.
45. **Alijanipour P**, **Bakhshi H**, **Parvizi J**. Diagnosis of periprosthetic joint infection: the threshold for serological markers. *Clin Orthop Relat Res*. 2013;471(10):3186–3195.
46. **Li H-K**, **Rombach I**, **Zambellas R**, **et al**. Oral versus Intravenous antibiotics for bone and joint infection. *N Engl J Med*. 2019;380(5):425–436.
47. **Elyasi S**, **Khalili H**, **Dashti-Khavidaki S**, **Mohammadpour A**. Vancomycin-induced nephrotoxicity: mechanism, incidence, risk factors and special populations. A literature review. *Eur J Clin Pharmacol*. 2012;68(9):1243–1255.

Author information:
F-J. Vandeputte, MD, Orthopaedic Surgeon
K. Corten, MD, PhD, Orthopaedic Surgeon
Department of Orthopaedic Surgery and Traumatology, Ziekenhuis Oost Limburg Genk, Genk, Belgium; European Hip Center, Westerlo, Belgium.

M. Gevers, MD, Research Fellow
H. Welters, MD, Orthopaedic Surgeon
Department of Orthopaedic Surgery and Traumatology, Ziekenhuis Oost Limburg Genk, Genk, Belgium.

Author contributions:
F-J. Vandeputte: Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing, Formal analysis, Conceptualization, Writing – original draft.
M. Gevers: Data curation, Formal analysis, Investigation, Writing – original draft.
H. Welters: Writing – review & editing.
K. Corten: Conceptualization, Supervision, Writing – review & editing.

Funding statement:
The authors received no financial or material support for the research, authorship, and/or publication of this article.

ICMJE COI statement:
F-J. Vandeputte reports consulting fees from Zimmer Biomet, Johnson & Johnson, and MedEnvision, payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events from Johnson & Johnson, and support for attending meetings and/or travel from Arthrex, all of which are unrelated to this study. K. Corten reports royalties or licenses, consulting fees, payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events, patents planned, issued or pending from Depuy Synthes and MedEnvision, and stock or stock options in MedEnvision, all of which are unrelated to this study.

Data sharing:
The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request

Ethical review statement:
The ethical committee approved this study (CTU nr Z-2021073), and all participants signed an informed consent.

Open access funding:
The open access fee was self-funded.

This article was primary edited by J. Scott.

This paper was presented at the International Hip Society 2024 Meeting in Athens, Greece.