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HIP ARTHROPLASTY

The worst-case scenario: treatment of periprosthetic femoral fracture with coexistent periprosthetic infection—a prospective and consecutive clinical study

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Abstract

Background The simultaneous occurrence of periprosthetic fracture (PPF) and periprosthetic joint infection (PJI) is among the most devastating complications in arthroplasty and carries the risk of limb loss. For the first time, this study will describe the characteristics, treatment concepts, and outcomes of this complication.

Methods Patients were consecutively included who were treated at our specialized interdisciplinary department between 2015 and 2016 with a PJI and an additional PPF of the hip. The treatment algorithm followed a three-step procedure: the complete removal of any foreign material (step 1), fracture stabilization by plate, intramedullary rod osteosynthesis or cerclages using an additional spacer (step 2), and reimplantation of a new prosthesis (step 3).

Results Overall, eight cases [four male, four female, mean age 77 years (55–91)] were included. The mean follow-up was 34 ± 8 months. The fractures included one PPF Vancouver B1, three B2/3, and four type C. Most frequent microbes were CNS (*Coagulase-negative staphylococci*) ($n = 4$), *Cutibacterium* ($n = 2$) and *Staphylococcus aureus* ($n = 2$). Mixed infections (≥ 2 microorganisms) occurred in five cases. The time between explanation and reimplantation was 42 ± 34 (range 7–123) days. A re-infection took place in one, a re-revision in four cases, and in five cases fracture healing was noticed. In all eight cases, freedom from the infection and limb preservation could be achieved.

Conclusion PPF in the case of a PJI is a devastating situation and a huge challenge. Extremity preservation should be the primary goal. The described procedure offers a possible solution.

Keywords Arthroplasty · Periprosthetic joint infection · Infection · Fracture · Complications

Background

Periprosthetic joint infections (PJI) and periprosthetic fractures (PPF) are among the most serious complications in arthroplasty. Both require a complex and structured therapeutic approach [1–5]. If both complications occur at the same time, one is faced with a seemingly unsolvable situation. The aging population with extended endoprosthetic care entails a higher risk of such complex situations occurring [6].

The inherent problem is the completely different and, in some aspect, contrary treatment concepts to address both

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entities, PJI and PPF. While PJI requires surgical infection eradication with complete removal of the prosthesis and all foreign materials, PPF needs fracture stabilization provided by internal fixation with foreign material. Data on this specific situation are scarce. Bottner et al. described a case, in which a modified hip disarticulation in combination with an above-knee amputation under the use of a temporary hip joint spacer was performed and consecutively recommended as a treatment option in case of periprosthetic infection accompanied by periprosthetic fracture [7]. Subsequently, the implantation of a particular total hip prosthesis into the thigh stump was employed in the second stage in this case report.

Limb amputation is always detrimental for the patient and considered a last stage salvage procedure. Therefore, current treatment concepts should implicitly avoid this procedure and include extremity-preserving approaches. Recent findings regarding biofilm fundamentals [4, 5, 8–10], biofilm-active antimicrobial therapy [3, 5, 9, 11, 12], one-stage uncemented septic revision strategies [13, 14], and more detailed knowledge of specific microorganisms [8, 12, 15, 16] provide encouragement for more daring surgical procedures.

In this case series, we describe eight cases with successful treatment of concomitant PJI and PPF with a limb-preserving strategy.

Methods

Study design

The prospective case series was carried out in a centralized department of a university clinic, exclusively specialized on PJI. Surgeons, microbiologists, pathologists, and infectiologists were involved in the interdisciplinary- and algorithm-based diagnosis and treatment approach for PJI [2, 4, 17, 18]. The study was approved by the internal university ethics committee and performed in accordance with the Declaration of Helsinki.

All patients were consecutively included who: (1) were treated at our specialized interdisciplinary department (2) between 2015 and 2016 (3) with the diagnosis of PJI (see below) and an additional periprosthetic fracture of the femur (4) with an available 2-year follow-up. The periprosthetic fractures were classified according to the Unified Classification System {Duncan, 2014 #16}. After discharge, patients were followed up clinically (mainly for signs of infection persistence) and radiographically every 3 months within the 1st year, then annually.

Treatment procedure

In all cases, the treatment algorithm follows a three-step procedure within a two-stage revision (Fig. 1). In general, at the first stage, complete removal of any foreign material, including the infected osteosynthesis and the prosthesis was carried out (step 1, Fig. 1). In addition, all avital bone fragments from the fracture zone were removed to avoid sequestration. Following this, fracture stabilization was achieved by plate osteosynthesis and in seven cases by the additional use of a custom-made spacer (step 2). The spacer bypassed the fracture zone and was loaded per 40 g polymethylmethacrylate (PMMA) with 0.5 g gentamicin and 2 g vancomycin. After regular wound consolidation, a decrease in the infection parameters and identification of the causative pathogen(s) and its susceptibility, the reimplantation was performed in the second stage (step 3) (Fig. 1). The interval between the first and second stage was either short (< 3 weeks) or long (≥ 3 weeks) depending on the course of the infection and the ability of the patient to mobilize.

Antimicrobial therapy was administered based on bacterial susceptibility and according to EUCAST criteria and the recommendations of the infectious disease's specialists and microbiologists of our specialized interdisciplinary team. The choice of antimicrobial treatment was based on previously published recommendations [17]. Figure 2 gives an overview of the administration of the antibiotics depending on the selected interval.

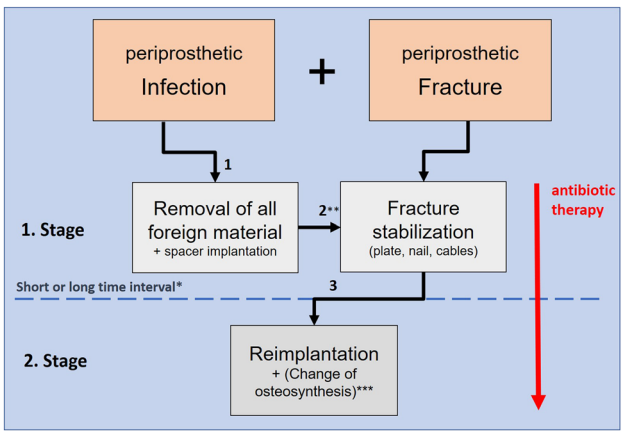

Fig. 1 Treatment scheme (three-step procedure) of the simultaneous occurrence of periprosthetic fracture and infection. In the first stage, removal of the prosthesis and all the foreign materials (step 1) and fracture stabilization (step 2) followed by the second stage, either at a short or long interval, the reimplantation of the new prosthesis (step 3). *Depending on the course of the infection and the ability to mobilize the patient, **new draping of the operating table and patient, ***according to the assessment of the surgeon and antibiotic activity against biofilm

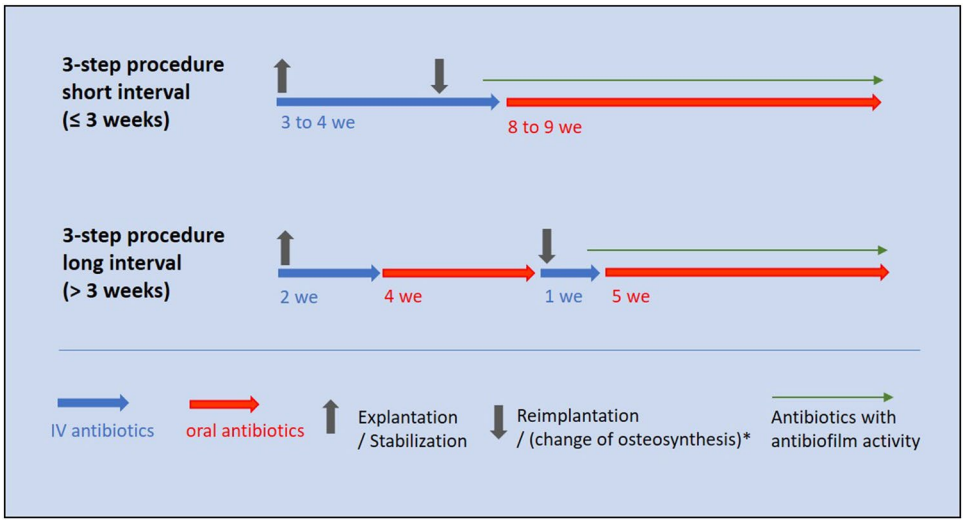

Fig. 2 Scheme of antibiotic therapy depending on the selected interval, *obligatory in the case of difficult-to-treat (DDT) pathogens

Definitions

PJI was defined on the basis of the proposed European Bone and Joint Infection Society (EBJIS) [19]: (1) fistula or purulence around prosthesis (2) > 2000/µl leukocytes in synovial fluid or > 70% granulocytes in synovial fluid (3) microbial growth in synovial fluid or ≥ 2 tissue samples or sonication fluid (> 50 CFU/ml) (4) Krenn and Morawietz type II or type III in periprosthetic tissue histology [20].

Infection persistence was defined according to the negative Delphi criteria of treatment success [21]: (1) no postoperative wound healing and fistula or infection recurrence by the same microbe/microbe spectrum (2) subsequent revision for infection after reimplantation surgery (3) PJI-related sepsis. Additionally (4) paraclinical and clinical signs of infection persistence were considered: early radiological signs of implant loosening in within the study period, persistent CRP > 1 mg/dl, clinical signs like redness, pain, hyperthermia, swelling, and loss of function [22].

Results

Overall, eight cases with PPF and PJIs could be included (Table 1). The mean follow-up was 34 ± 8 months. All patients were treated via a two-stage revision using the presented three-step procedure. In four of the eight patients, a short interval of ≤ 3 weeks was used. *Coagulase-negative staphylococci*, *Cutibacterium* (*formerly Propionibacterium*) *acnes*, and *Staphylococcus aureus* were the most common bacteria. More than half of the cases had colonization with more than two microbes. The va-lcp condylar plate (DePuy Synthes, Warsaw, Indiana, USA) was the most frequently used for fracture stabilization. A re-infection was caused in one case by an acute hematogenous PJI involving *Streptococcus dysgalactiae*, treated by irrigation, debridement, and exchange of modular components. Any re-revision was necessary in four cases involving the already mentioned early infection, a revision of a postoperative hematoma, a secondary trochanter dislocation with the need of refixation by means of plate osteosynthesis, and a revision of an aseptic stem loosening 3.5 months postoperatively. Fracture healing was observed in five cases (Table 2).

To clarify the complexity of the treatment of the combined appearance of periprosthetic fracture and infection, four cases will now be presented in more detail**.**

Case 1 The first patient was an 81-year-old man who suffered from a periprosthetic femoral fracture of the left hip, type Vancouver C, due to a traffic accident. Before the accident, the patient had no symptoms at the site of the prosthesis, which was implanted 12 years before. In a primary care hospital, open reduction and internal fixation were performed by means of plate osteosynthesis. Two weeks after initial primary wound healing, signs of infection with erythema swelling and a fistula in the area of the plate occurred. Immediately, irrigation and debridement were performed. However, prolonged wound secretion and signs of infection persisted, and the patient was referred to our hospital. Unfortunately, the patient fell before referral and suffered from an additional distal femoral fracture (Fig. 3a). At our institution, revision with removal of the plate and prosthesis was carried out. The previously performed hip joint aspiration was inconspicuous.

Nevertheless, the decision to remove the prosthesis was made because of the direct proximity of the infected plate to the prosthesis. Meticulous debridement, irrigation, and removal of avital bone fragments to prevent sequestration were performed (Fig. 3b). After re-draping and the use of newly set operating tables, the fracture stabilization was

Table 1 Patient demographics, fracture type, microbe spectrum, and the outcome

Patient information	
Mean age (years) ± SD	77 ± 12
Female/male	4/4
Mean age-adjusted CCI[a] ± SD (range)	5.1 ± 1.7 (2–8)
Previous septic revision rate % (*n*)	37.5 (3)
Type of fracture	
Vancouver B1	1
Vancouver B2/3	3
Vancouver C	4
Microbes	
Microbes found in ≥ 2 PJIs	CNS[b] × 4 *Staphylococcus aureus* × 2 *Cutibacterium acnes* × 2 *Haemophilus* × 1 *Streptococcus anginosus* × 1 *Klebsiella oxytoca* × 1 *Corynebacterium* sp. × 1 *Enterococcus faecalis* × 1
DTT[c] rate % (*n*)	12 (1)
Mixed infections (≥ 2 microbes) % (*n*)	63 (5)
Treatment	
PJI	
Two-stage (three-step procedure)	8
Spacer	7
Interval (short[d]/long)	3/5
Mean interval (range) ± SD (range)	42 ± 37 (7–123)
Total time of hospital stay ± SD	33.8 ± 5.9
PPF	
Plate (VA-LCP) % (*n*)	62.5 (5)
Intramedullary rod/pin % (*n*)	37.5 (3)
+ Tension band/cerclages % (*n*)	87.5 (7)
Plate and rod/pin % (*n*)	37.5 (3)
Plate exchange (reimplantation) % (*n*)	12,5 (1)
Strut graft (reimplantation) % (*n*)	62.5 (5)
Follow-up	34 ± 8 months
Re-infection rate % (*n*)	12.5 (1)
Total re-revision rate % (*n*)	37.5 (4)
Fracture healing rate % (*n*)	62.5 (5)

[a]Charlson comorbidity score

[b]Coagulase-negative staphylococci

[c]DTT (difficult-to-treat organisms)

[d]≤ 3 weeks

performed using cerclages and a variable angle locking compression plate (4.5 mm VA-LCP curved condylar plate, DePuy-Synthes, Warsaw, Indiana, USA). A custom-made spacer armed with a long-bent Steinmann pin bridging the fracture zone was additionally implanted (Fig. 3c). Two weeks after explanation, the reimplantation was performed when soft-tissue conditions were unremarkable and systemic inflammatory parameters were almost normalized. A short interval was given due to the patient's poor ability to mobilize with the spacer. Intraoperatively obtained tissue samples showed growth of *Corynebacterium* spp. and *Staphylococcus hominis*. Immediately after surgery, intravenous antibiotic therapy with 3 × 3 g ampicillin and sulbactam and 1 × 700 mg daptomycin was initiated and maintained until reimplantation. After 14 days, a revision cup (TMARS, Zimmer Biomet, Warsaw, Indiana, USA) and a modular revision stem (Revitan® Revision Hip System, Zimmer Biomet, Warsaw, Indiana US) which was distally cemented due to the destroyed isthmus were implanted at the second stage. A 36 mm PE-CE-bearing system was used (Fig. 3d, e). The VA-LCP plate was left in place and debrided and irrigated. Disturbing screws for stem implantation were removed, and additional attachment plates were used.

Additionally, the fracture of the proximal femur was stabilized using cerclages and tension band wiring. At hospital discharge, the intravenous antimicrobials were switched to oral administration of 2 × 300 mg rifampin in combination with 2 × 100 mg doxycycline. This combination was administered for a total of 10 weeks. At the last visit, no paraclinical or clinical signs and symptoms of infection were present so no further operation was necessary, and the patient was fully mobilized using a rollator.

Case 2 The second patient was an 83-year-old woman with bilateral total hip arthroplasty, who had fallen at home and suffered from a periprosthetic femoral fracture Vancouver B2 at the right hip. Revision surgery with stem revision and plate osteosynthesis was performed elsewhere. Four weeks after surgery, erythema and swelling with wound dehiscence at the surgical site occurred. Repeated debridement and irrigation were carried out, due to persistent signs of infection. In addition, the fracture did not heal, and the mobilization was insufficient. After 4 weeks, the patient was transferred to our hospital (Fig. 4a). The plate and prosthesis were first removed and debridement and irrigation performed. After re-draping and the use of fresh operating tables, the fracture stabilization was performed with cerclages and a variable angle locking compression plate (4.5 mm VA-LCP curved condylar plate, DePuy-Synthes, Warsaw, Indiana, US). A vancomycin- and gentamicin-loaded cement tube was inserted into the femur so that the fracture zone was adequately passed. The hip was left in a Girdlestone situation (Fig. 4b). Intraoperatively obtained tissue samples showed

Table 2 Overview over the eight patients with treatment strategy, identified microbes and follow-up

Patient Age	Pre-revisions (*n*)	History	Explanations and fracture stabilization	Reimplantation	Interval (days)	Microbes	Antibiotic therapy iv Antibiotic therapy oral	Complications	Follow-up (months)
1, male 55	4	Multiple pre-revisions with two-stage exchange, chronic instability, diaphyseal fracture after reimplantation	Explantation, PMMA spacer with AO rod, cerclages	Reimplantation of an uncemented revision cup and modular revision stem, fracture stabilization with VA-LCP	61	*Haemophilus parainfluenza* (explantation), *Propionibacterium acnes* (reimplantation)	Unacid, vancomycin, meropenem/ciprofloxacin, rifampicin, amoxicillin	Acute hematogenous infection (periodontitis) after 4 months, DAIR (debridement, antibiotics and implant retention) and tooth extraction	29
2, male 81	1	Infected femoral nonunion with fistula after plate osteosynthesis (OS) of a Vancouver C fracture after car accident, fresh periimplant distal femur fracture after fall in rehab clinic	Explantation, plate removal, pseudarthrosis revision and sequestrectomy, spacer, osteosynthesis with VA-LCP	Reimplantation of an uncemented revision cup and modular revision stem, leaving the plate, tension band wiring of the great trochanter	14	*Staphylococcus hominis*, *Corynebacterium* sp.	Unacid, cubicin/doxycyclin, rifampicin		32
3, female 83	3	Plate osteosynthesis and stem exchange in periprosthetic fracture Vancouver B2 with following infection	Explantation, plate removal, pseudarthrosis revision and sequestrectomy intramedullary spacer and osteosynthesis using VA-LCP	Reimplantation of an uncemented revision cup and modular revision stem, leaving the plate, cortical strut allografting	19	*Staphylococcus epidermidis*	Unacid, daptomycin/cotrim forte, rifampicin		27
4, male 77	4	Dislocated femoral fracture after resection arthroplasty for periprosthetic joint infection (PJI)	Femur fracture in rehab-clinic 24 days after explantation and resection arthroplasty	Reimplantation of an uncemented revision cup and modular revision stem, osteosynthesis using VA-LCP, medial cortical strut allografting	26	*Propionibacterium acnes*	Unacid, vancomycin/cotrim forte, rifampicin	Stem revision caused by stem migration 6 months postoperatively	40
5, female 75	3	Periprosthetic femur fracture Vancouver B1 treated with double plate OT and concomitant PP infection, incompletely explanted	Explantation, plate and spacer removal, PMMA spacer with AO rod	Reimplantation of an uncemented revision cup and modular revision stem, lateral cortical strut allografting, cerclages	35	*Staphylococcus epidermidis*, *Enterococcus faecalis*	Vancomycin, ampicillin, gentamicin/amoxicillin, cotrim forte, rifampicin		29
6, female 91	5	Multiple revisions due to fractures and hip joint infections, spacer removal and removal of a bony window (sequestration) in the femoral diaphysis, femur fracture at the level of the defect on the 5th postoperative day	Femur fracture 5 days after spacer removal	Reimplantation of an uncemented revision cup and modular revision stem, lateral cortical strut allografting, tension band wiring, cerclages	7	*Staphylococcus epidermidis*, *Klebsiella oxytoca*	Ceftriaxon, cubicin, vancomycin, unacid/doxycyclin, rifampicin, ciprofloxacin	Postoperative hematoma and irrigation 13 days after surgery	27
7, male 80	6	Multiple revisions caused by PJI, cup revision caused by aseptic loosening, traumatic periprosthetic fracture (PPFX) with additional PJI	Prosthesis removal and resection arthroplasty with fracture stabilization using wire cerclages	Reimplantation of an reconstruction ring and modular revision stem, cerclage exchange of the femur with titanium band cerclages	123	*Staphylococcus aureus*, *Propionibacterium avidum*	Vancomycin, unacid, daptomycin/rifampicin, levofloxacin		40
8, female 74	1	Stem revision several years ago, septic loosening with additional PPFX Vancouver B	Removal and fracture stabilization with AO rod and wire cerclages	Reimplantation of an uncemented revision cup and modular revision stem, cerclage exchange of the femur on titanium band cerclages	48	*Propionibacterium acnes*	Vancomycin, unacid/rifampicin, levofloxacin	Trochanter dislocation, refixation by plate osteosynthesis (claw plate with cerclages)	51

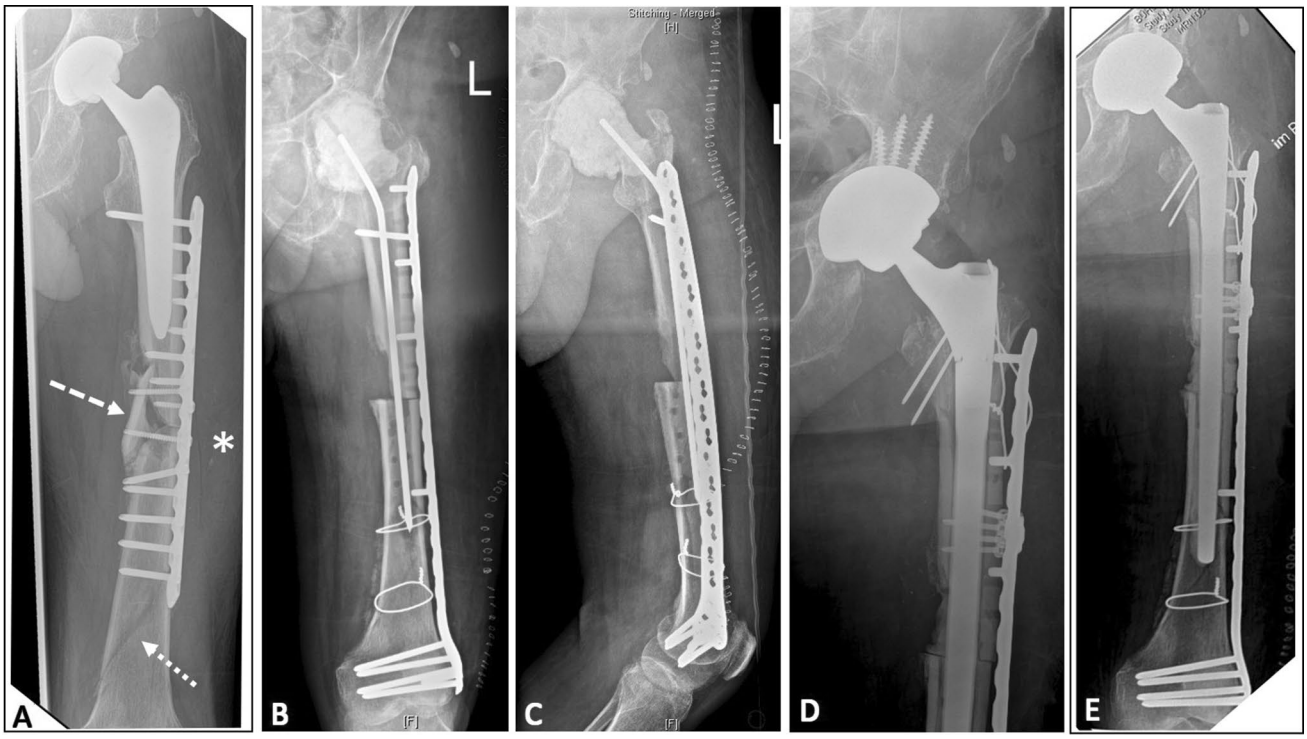

Fig. 3 The X-rays of case 1. **a** Periprosthetic femoral fracture Vancouver C, which was initially treated with a plate osteosynthesis in another hospital. Dotted arrow: distal femoral fracture, additionally suffered shortly before transfer to our hospital, dashed arrow: initial periprosthetic fracture (due to a traffic accident) with a single avital bone fragment. Asterisk: location of the wound dehiscence. **b**, **c** Situation after plate and prosthesis removal, fracture stabilization using VA condylar plate and custom-made spacer. **d**, **e** Reimplantation of a revision cup and a distally cement fixated modular revision stem, retaining the VA condylar plate after 2 weeks

significant growth of *Staphylococcus epidermidis* in multiple specimens. Immediately after surgery, intravenous antibiotic therapy with 3 × 3 g ampicillin/sulbactam and 1 × 700 mg daptomycin was initiated and maintained for 14 days.

At second stage after 12 days, the reimplantation was performed using a revision cup (TMARS, Zimmer Biomet, Warsaw, Indiana US) and a modular revision stem (Revitan® Revision Hip System, Zimmer Biomet, Warsaw, Indiana, US) which was also cemented distally due to the destroyed isthmus. The VA-LCP plate was left in place and debrided and irrigated in the second step. Disturbing screws for stem implantation were removed and replaced by attachment plates. In this patient, we additionally used a femoral strut graft of approximately 20 cm which was ventrally placed onto the femur bridging the fracture zone and fixed by cerclages (Fig. 4c). After discharge from the hospital, the antibiotic treatment was switched to oral administration of 2 × 300 mg rifampin and 2 × 960 mg co-trimoxazole (sulfamethoxazole and trimethoprim). This regimen was administered for a total of 10 weeks. So far, no further operation was necessary after a follow-up of 2 years. The patient is fully mobilized.

Case 3 The third patient was a 55-year-old craftsman who presented with a chronically dislocated hip prosthesis, a periprosthetic infection and a periprosthetic femoral fracture (Fig. 5a). Two years before, the patient had received an uncemented total hip arthroplasty due to a femoral head necrosis. Since then, he had been revised for a total of four times due to recurrent periprosthetic infections and dislocations in different hospitals. *Haemophilus parainfluenzae*, *Streptococcus anginosus,* and *Cutibacterium acnes* could be identified preoperatively. In the first stage, the prosthesis was removed, the fracture stabilized with cerclages, and a custom-made spacer armed by a 350 mm AO rod in combination with a bent Steinmann pin was placed (Fig. 5b). The spacer was loaded with vancomycin and gentamicin. The AO rod also served to bridge the fracture. Perioperative i.v. antibiotic therapy using daptomycin and meropenem was changed to ciprofloxacin and co-trimoxazole as oral therapy after the patient discharge until reimplantation surgery. After 8 weeks, a revision cup and a modular revision stem were implanted using a 36 mm PE-ME-bearing system. A 4.5 mm VA-LCP Curved Condylar Plate was additionally inserted (Fig. 5c). I.v. antimicrobial therapy with vancomycin and

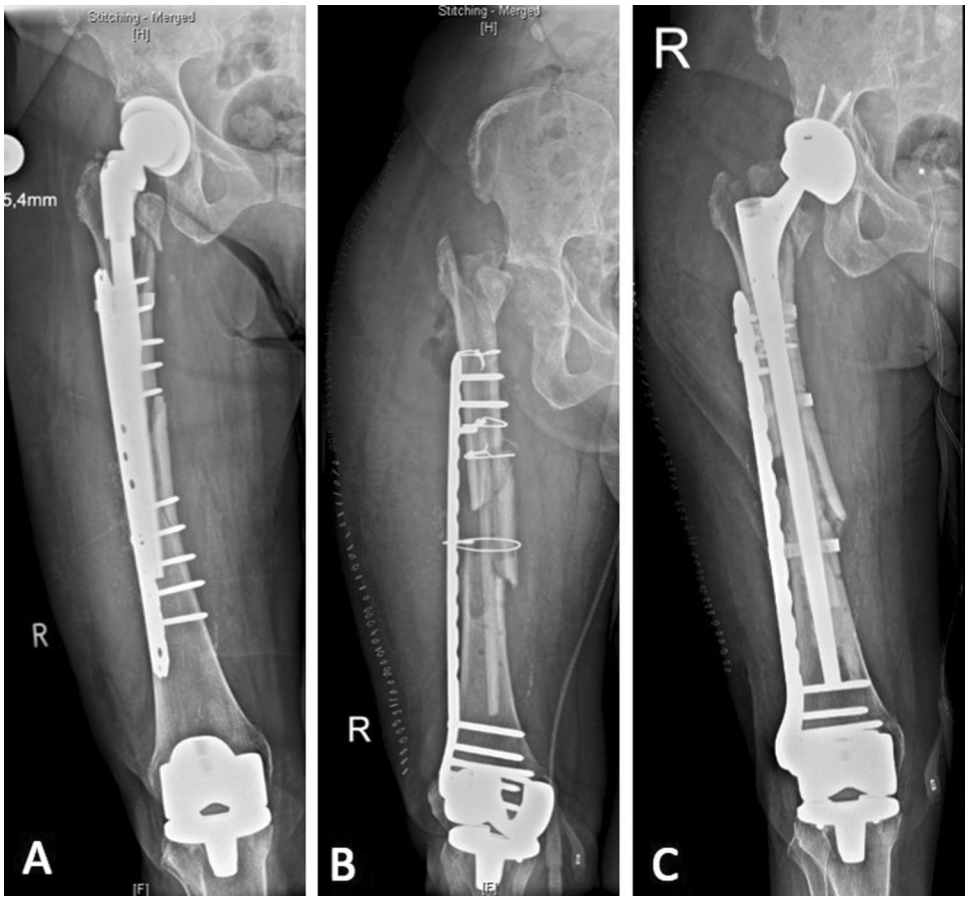

Fig. 4 X-rays of case 2. **a** Periprosthetic infection after the treatment of a periprosthetic femoral fracture type Vancouver C, with a plate osteosynthesis and stem revision, **b** situation after plate and prosthesis removal, fracture stabilization using a 4.5 mm VA-LCP condylar plate and custom-made spacer (cement rod). **c** Reimplantation of a revision cup and a distally cement fixated modular revision stem, retaining the VA condylar plate after 2 weeks

meropenem were switched to orally administered rifampin and amoxicillin for another 8 weeks after the patient's discharge. After 6 months, the patient presented to our hospital with an acute hematogenous PJI involving *Streptococcus dysgalactiae* at the left hip endoprosthesis site. Irrigation, debridement, and exchange of modular components were performed immediately. The diagnosis of acute PJI originating from the oral cavity was confirmed after dental assessment revealed severe periodontitis. As a result, sanitation of the patient's dental foci was initiated, which had obviously been responsible for the recurrent infections for years. The patient was discharged after 2 weeks of i.v. treatment and administered with 3 × 1 g amoxicillin for a total of 12 weeks.

Case 4 The fourth patient was a 75-year-old female who received her primary hip prosthesis 22 years ago and had to undergo revision surgery for periprosthetic fractures two times since then. She presented herself with clinical symptoms of a chronic periprosthetic joint infection to a foreign hospital. There her first periprosthetic joint infection could be verified by identifying *S. epidermidis* and *Enterococcus faecalis* in a joint aspiration. Consequently, a two-stage exchange was performed. After the prosthesis reimplantation, she then suffered a periprosthetic femur fracture type Vancouver B1, which was treated with an ORIF open reduction plate (Fig. 6a, b), which then broke in the following course (Fig. 6c). Following the ORIF plate break, a double plate fixation was performed in the foreign hospital, which then showed signs of re-infection (Fig. 6d). Subsequently, only the removal of the shaft was carried out leaving the plates and socket (Fig. 6e). In this condition, the patient was transferred to our department, where we revised the patient and explanted the plates and socket. Using a new operating table and re-covering the patient, we implanted a vancomycin-loaded PMMA spacer with 350 mm AO rod bypassing and fixing the fracture zone (Fig. 6f). After 35 days, an uncemented revision cup and modular revision stem were re-implanted, combined with a lateral cortical strut allografting and cerclages (Fig. 6g). In our department, vancomycin, ampicillin and gentamicin were applied i.v. during her hospital stay and switched to oral therapy after her release for a total of 28 days [amoxicillin (1 g), co-trimoxazole (960 mg), rifampicin (300 mg)]. The patient did not suffer further complications, was mobilized well, and could be released 14 days after the reimplantation.

Fig. 5 X-rays of case 3. **a** Chronically dislocated hip prosthesis with a PJI and a periprosthetic femoral fracture. **b** Situation after revision with prosthesis removal, fracture stabilization by means of cerclages and the use of a custom-made spacer. **c** Reimplantation of a revision cup, a distally fixating modular revision stem, and additional support for the initial consolidated fracture with a variable angle locking compression plate

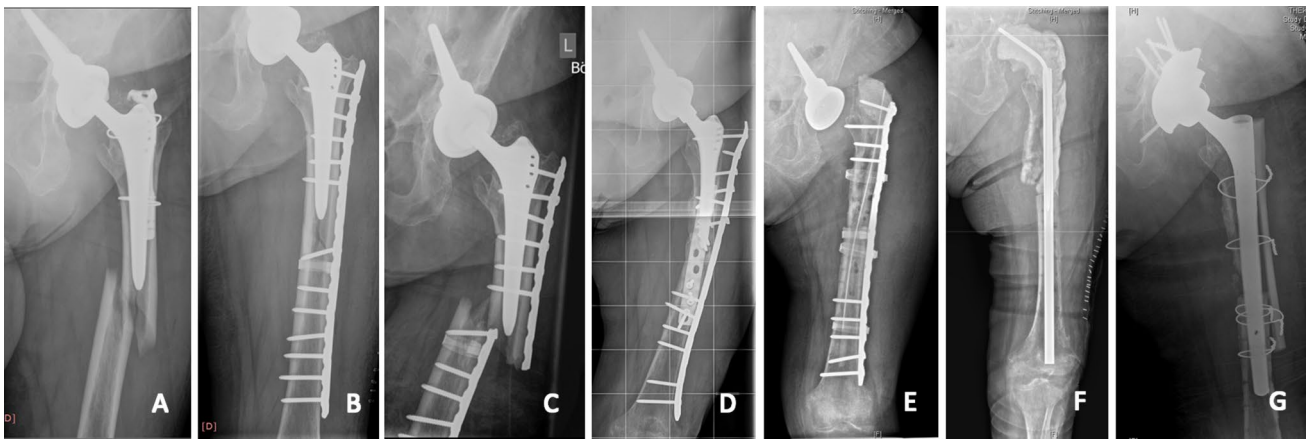

Fig. 6 X-rays of case 4. **a** Periprosthetic femur fracture Vancouver b1 in a foreign hospital after a prosthesis reimplantation in the course of a two-stage exchange. **b** Treatment with ORIF open reduction plate. **c** Plate breakage. **d** Double plate fixation with subsequent PJI. **e** Removal of stem only with infection persistence Transfer to our hospital. **f** Revision with socket and plates removal, and implantation of a custom-made vancomycin-loaded PMMA spacer with a 350 mm AO rod bypassing and fixing the fracture zone spacer being implanted. **g** Reimplantation of the new total hip revision prosthesis after 35 days

Discussion

Periprosthetic joint infection in the presence of a periprosthetic fracture is an extremely challenging situation for the patient and the treating surgeons. One of the main goals of the treatment is limb salvage and the restoration of an infection-free, well-functioning and stable joint. The presented eight cases demonstrate, that even in such complex situations, a successful infection and fracture treatment was possible with the preservation of the extremity. Two-stage revision with immediate fracture stabilization after removal of the infected prosthesis and the following reimplantation of a new prosthesis after a short or long interval is considered the essential key to success. The utmost challenge is the conflicting approach of infection eradication by the removal of the entire hardware including prosthesis and the simultaneous need for fracture stabilization by the insertion of osteosynthetic material into an infected area. From our point of view, a direct osteosynthesis to ensure adequate fracture healing as well as to obtain bony stability—also necessary for infection therapy—is inevitable. The time of reimplantation depends on one hand on the infection control reflected by the decrease in infection parameters and on the other hand on the mobilization capacity of the patient.

One of the key points of treatment is an excellent combination of surgical and antimicrobial therapy. Our infection department is collaboratively managed by a team of surgeons and infectious disease specialists [23]. Thus, in addition to a highly specialized surgery, an optimized and concerted antimicrobial therapy is required, which takes into account the causing pathogen(s) including susceptibility, the choice of antimicrobial substances with adequate bone penetration, biofilm and bactericidal activity. Side effects and interactions with concomitantly administered drugs require continuous monitoring of the patients and immediate reaction if adverse effects occur. Overall, new insights into biofilm formation and its therapy have also encouraged joint-preserving operations even in most complex and almost hopeless situations [3–5, 9, 10].

Recent studies demonstrated good outcomes after one-stage uncemented revision [13, 14], whereby the insertion of an osteosynthesis immediately after a septic prosthesis removal is feasible. Furthermore, we meanwhile know more about the antibiotic susceptibility of different pathogens and may therefore be more specific regarding the antibiotics required, the optimal synergistic combinations, and the duration of therapy [8, 11, 12, 15, 16].

One of the main limitations of this study is the relative low number of cases. However, this is due to the low incidence of the coexistence of periprosthetic joint fracture and infection. In total, there is a lack of literature regarding this issue. The only publication known to us describes only two cases and is more than ten years old [7].

It can be assumed that due to the demographic evolution of the population in Western countries and the associated increase in the number of patients with a prosthesis, the incidence of these complex situations with concomitant PJI and PII will increase.

Conclusion

Periprosthetic fracture in the case of a periprosthetic infection is a devastating situation and a huge challenge for the treating team. The difficulty lies in simultaneous fracture stabilization and infection eradication, whose synergistic execution is the key to success. We recommend a three-step therapeutic algorithm within a two-stage procedure. In the first stage, all foreign materials are removed (step 1), followed by fracture stabilization (step 2) and then, after a short or long interval, reimplantation of the prosthesis (step 3). A lot of experience and highly specialized interdisciplinary centers are essential for successful treatment. The preservation of the extremity should always be the primary goal and sought first.

Author contributions Michael Müller, Daniel Karczewski: wrote the manuscript, Michael Müller, Daniel Karczewski: collected the data, Michael Müller, Tobias Winkler, Sven Märdian, Andrej Trampuz, Nora Renz and Carsten Perka performed the antimicrobial and surgical therapy, Michael Müller, Tobias Winkler, Sven Märdian, Andrej Trampuz, Nora Renz and Carsten Perka developed the surgical and antimicrobial concepts.

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Compliance with ethical standards

Conflict of interest Michael Müller, Sven Märdian, Andrej Trampuz, Daniel Karczewski, Nora Renz, Tobias Winkler and Carsten Perka declares no competing interest.

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