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PROSTHETIC JOINT INFECTION (S NODZO AND N FRISCH, SECTION EDITORS)

# The Role of One-Stage Exchange for Prosthetic Joint Infection

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## Abstract

**Purpose of Review** In an era of increasing numbers of hip and knee replacements, strategies to manage prosthetic joint infection (PJI) that are effective at infection control with good patient-reported outcomes and cost containment for health systems are needed. Interest in single-stage exchange for PJI is rising and we assess evidence from the last 5 years related to this treatment strategy.

**Recent Findings** Only five series for total knee replacement and ten series for total hip replacement have been reported in the last five years. More review articles and opinion pieces have been written. Reinfection rates in these recent studies range from 0 to 65%, but a meta-analysis and systematic review of all studies showed a reinfection rate of 7.6% (95% CI 3.4–13.1) and 8.8% (95% CI 7.2–10.6) for single-stage and two-stage revisions respectively. There is emerging evidence to support single-stage revision in the setting of significant bony deficiency and atypical PJIs such as fungal infections.

**Summary** Prospective randomised studies are recruiting and are necessary to guide the direction of single-stage revision selection criteria. The onus of surgical excellence in mechanical removal of implants, necrotic tissue, and biofilms lies with the arthroplasty surgeon and must remain the cornerstone of treatment. Single-stage revision may be considered the first-line treatment for all PJIs unless the organism is unknown, the patient is systemically septic, or there is a poor tissue envelope.

**Keywords** Prosthetic joint infection · Single-stage revision · Revision hip replacement · Revision knee replacement

## Introduction

According to projections, total hip (THA) and knee (TKA) arthroplasty numbers will increase significantly worldwide in the coming decades [1–5]. Both operations are very successful procedures with proven effectiveness both clinically and economically [6, 7]. Infection of the implanted prosthesis is a rare event but a leading cause for revision surgery. Prosthetic joint infection (PJI) incidence ranges from 0.5 to 2% [8–11]. The rate of PJI has geographical variation and is influenced by patient factors such as body mass index (BMI) [12–14]. As newer regions respond to patient demand for joint replacement, and as BMI continues to rise in developed and developing countries, the volume of PJIs are predicted to increase [15].

Revision surgery for infection is more expensive than aseptic revision; therefore, methods to reduce expenditure while achieving acceptable results should be considered for future PJI demands [16–18]. Acute PJI may be managed with debridement antibiotics and implant retention (DAIR), but two-stage revision arthroplasty with appropriate antibiosis remains the gold standard surgical treatment for chronic hip and knee PJI in most countries [19]. Two-stage surgery is costly for the patient and health care system that requires two admissions and occasionally a period of restricted mobility. One-stage exchange revision arthroplasty for chronic PJI is a single procedure that offers advantages over two-stage surgery. It is not a new treatment and was described in Sweden and Germany 40 years ago [20, 21]. The introduction of antibiotic-loaded cement allowed surgeons to deliver local antibiotics and reimplant definitive prostheses in one sitting. Fewer surgeons in the USA were using cement for definitive implant fixation, and this "North Atlantic divide" perhaps limited single-stage acceptance [22]. A recent systematic review and meta-analysis showed that success rates of one-stage revision (7.6% reinfection) were similar to those of two-stage revision

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(8.8% reinfection) surgery with similar clinical outcome scores [23••]. The purposes of this review are to describe the advantages of single-stage exchange for PJI and to assess whether perceived advantages of a one-stage procedure are being borne out in the literature within the last 5 years. We shall describe our surgical technique and inclusion criteria and assess the evidence for expanding these criteria. Finally, we will present our institutional results using single-stage exchange as part of our PJI treatment armamentarium, and present other authors' experiences using similar techniques.

## Prosthetic Joint Infection Diagnosis and Classification

We follow the international consensus meeting criteria for diagnosing PJI [24]. For patients with a diagnosis within 30 days of index surgery, or 3 weeks of infectious symptom onset and no wound sinus, DAIR is our preferred strategy [19]. Patients that present with chronic PJI are considered for single-stage exchange if they meet the inclusion criteria [1]. An early and important step on the decision tree is the patient's general condition and suitability for a prolonged single-stage exchange [25]. Resection arthroplasty, arthrodesis, and amputation are salvage procedures for resistant PJI that are not the subject matter of this review.

## Surgical Technique of Single-Stage Exchange for Prosthetic Joint Infection

We have previously described our technique and briefly outline the steps of preparation, initial debridement, "time-out," and reimplantation here (Figs. 1 and 2) [26]. Patients are positioned appropriately for hip or knee revision surgery with general or regional anaesthesia. Tranexamic acid (1 g intravenously at induction) is used. Tourniquets are applied but not inflated for knee surgery. Pre-operative antibiotics are held until fluid and tissue samples are taken. Previous incisions are marked with methylene blue and are included as appropriate to allow exposure, implant removal, and reimplantation without compromising wound healing. The skin is prepared twice with iodine povacrylex and isopropyl alcohol surgical solution (3M™ DuraPrep™, Maplewood, MN, USA). The skin is covered by an antimicrobial incision drape (3M™ Ioban™ 2).

We prefer a medial parapatellar approach to the knee and posterolateral approach to the hip but adapt the approach according to acuteness of the last surgery. Sinuses and fistulae are incorporated in the approach and radically excised. Five tissue samples and fluid, if present, are sent in culture medium bottles to microbiology. Separate samples are sent for histology. Parenteral antibiotics are administered according to the pre-operative plan with our microbiologist. Extensile exposure techniques are used liberally but care is taken to avoid unnecessary bone loss with implant removal. An aggressive debridement of periprosthetic tissue is performed and is the cornerstone of this technique. All cement, necrotic material, and biofilms are removed such that only healthy bleeding tissue remains. Reaming of both the tibia and femoral canals is performed. After debridement, 12 L of warm 0.9% saline via low-pressure pulsatile lavage is used to clean the field. Brushes are used to mechanically debride femoral and tibial canals. Aqueous povidone-iodine (1% available iodine) solution is poured into the wound and left to settle for up to 5 min (Fig. 1). This is washed away with 0.9% sodium chloride solution and a mix of 100 mL of 3% hydrogen peroxide and

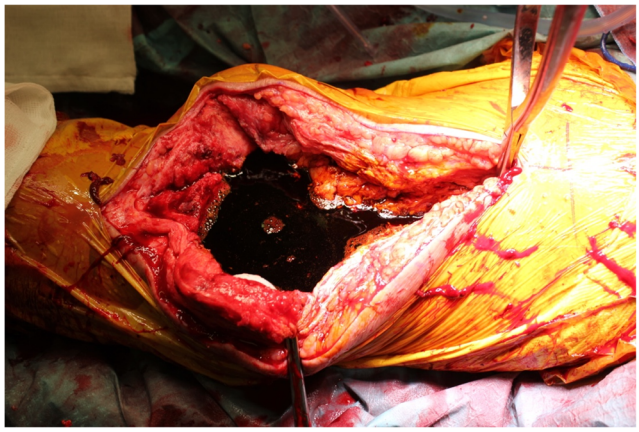

**Fig. 1** Single exchange of total knee replacement demonstrating aqueous povidone-iodine (1% available iodine) solution in the wound after implant removal and excision of necrotic tissue. The solution is left to settle for up to 5 min and is washed away with 0.9% sodium chloride solution

**Fig. 2** A mix of 100 mL of 3% hydrogen peroxide and 100 mL of sterile water solution is applied to the surgical field after the povidone-iodine bath. The hydrogen peroxide mix is washed away by 0.9% sodium chloride and povidone-iodine-soaked gauzes are packed into the wound. The wound edges are approximated with a continuous nylon and the field is dried. A new antimicrobial drape is used to seal the wound and the surgical team un-scrubs and prepares for the reimplantation

100 mL of sterile water solution is applied (Fig. 2). The hydrogen peroxide mix is washed away by 0.9% sodium chloride. Finally, povidone-iodine-soaked gauzes are packed into the wound. The wound edges are approximated with a continuous nylon and the field is dried. A new antimicrobial drape is used to seal the wound. Drapes are removed from the patient, used surgical sets are removed from the operating room, and the entire surgical team disrobes.

New equipment is brought into the operating room, the team scrubs, and the patient is cleaned with surgical solution and draped as before. The wound is then opened, sutures discarded, and the entire surgical field undergoes a further lavage. The same dose of antibiotics and tranexamic acid used at induction is re-administered at this stage. Definitive implantation occurs and topical antibiotics are delivered. The original successes of this technique were made possible by antibiotic-loaded cement and this continues today at some large centres [20, 21, 27]. Some authors deliver antibiotics topically in powder form, mixed with allograft as calcium sulfate beads, or add them to the cement powder polymer at mixing [26, 28–32]. Watertight, layered closure is performed and drains are used.

## Advantages of Single-Stage Exchange for PJI

The main advantage of single-stage exchange for PJI is that explantation and reimplantation is performed with one procedure. The pros of a single-stage procedure may be reduced overall cost and total operative time compared to two-stage revision for PJI. Cost reduction has been proven for THA single-stage revision, but has not being tested for TKA, and there have been no further studies within the last 5 years looking at cost-effectiveness for either joint [18, 33]. In a recent retrospective observational study of single-stage revision for THA PJI from three institutions involving 27 patients, the mean estimated blood loss was 739 mL (range, 150–1300 mL), and the mean operative time was 98 min (range, 66–147 min) [30]. There are no recent comparative studies assessing operative time or cumulative hospitalisation for single- and two-stage revision for PJI.

It has been suggested that arthrofibrosis is reduced and range of motion is increased in TKA PJI treated with single-stage versus two-stage revision [34]. There are no studies that test this hypothesis, but extrapolations may be made from functional scores. We have previously demonstrated improved Knee Society Scores in single-stage exchange procedures as compared with two-stage revisions for TKA PJI; however, there were different inclusion criteria for the groups [35]. There is scant evidence of a demonstrable improved function after single-stage revision compared with two-stage surgery. A retrospective comparative study of THA PJIs reported Harris hip scores of 77 ± 14 in single-stage revision and 60 ± 30 in the two-stage revisions but the difference was not statistically significant ($P = 0.14$) [36]. Similarly, the UCLA activity score was not different: 4.0 ± 1.4 in the single-stage group and 4.2 ± 2.0 in the two-stage group ($P = 0.74$) [36]. One study specifically compared patient-reported outcomes (PROMs) for patients undergoing single-stage or two-stage revision TKA [37]. The authors interrogated PROM data collected alongside data from the National Joint Registry (NJR) for England and Wales. They compared 33 patients and 89 patients at least 6 months after a single-stage or two-stage revision for TKA PJI respectively. There were no demographic differences between the groups and post-operative Oxford knee score (OKS), Euroqol-5D (EQ5D), and patient satisfaction were not different. The authors concluded that the decision to perform single- or two-stage surgery should be based on rate of reinfection or cost-effectiveness, and that two-stage surgery should remain the gold standard.

Berend et al. have previously reported a high mortality rate with two-stage revision for PJI [38]. In this non-comparative retrospective review of 205 THA PJIs, the authors reported a 90-day mortality rate of 4% after the first stage and a 7% mortality rate prior to second stage implantation. Mortality rate following the second stage of revision surgery for PJI was not reported. As a result, it is impossible to conclude that mortality may be higher in a two-stage as compared to a single-stage surgery since the patients that died had undergone a single procedure. Further comparative studies are required to determine if mortality is higher after the second-stage or after a single-stage exchange.

It is unclear if the morbidity of single-stage revision is less than the morbidity of two-stage revision. Klouche et al. did not show a difference in complications between single-stage and two-stage revision surgeries [39]. Choi et al showed higher complication rate requiring surgery amongst patients that underwent two-stage surgery compared to single-stage exchange surgery, but this did not achieve significance [36].

## Recent Results of Single-Exchange for Chronic Infection

It is difficult to compare results of single-stage revision from different series as the definition of success varies [40]. One of the early centres to adopt single-stage revision, the ENDO Klinik at Hamburg, Germany, defines success as no subsequent surgical intervention for infection after reimplantation, and/or no clinical and laboratory signs of recurrence of infection [41]. Recent results of observational, retrospective, and comparative studies show that single-stage exchange for PJI is gaining international acceptance with results showing non-inferiority compared to two-stage surgery when strict inclusion criteria are applied (Table 1 and 2). Within the last 5 years, there have been ten THA and five

**Table 1** International criteria for one-stage exchange. *UCLH*, University College London Hospital; *ISDA*, Infectious Diseases Society of America

| UCLH criteria for one-stage exchange [26] | ENDO Klinik criteria for one-stage exchange [41] | Infectious Diseases Society of America criteria for one-stage exchange [19] | International consensus meeting criteria for one-stage exchange [42] |
|---|---|---|---|
| | | Total hip arthroplasty | |
| Organism identified pre-operatively | Organism identified pre-operatively | Organism identified pre-operatively | Organism identified pre-operatively |
| Organism susceptible to antibiotics | Organism susceptible to antibiotics | Organism susceptible to antibiotics with high oral bioavailability | Organism susceptible to antibiotics |
| Good soft tissue | | Good soft tissue | |
| | | Good bone stock | |
| | | Bone grafting not required | |
| | | Antibiotic-loaded cement used for definitive implant fixation | |

TKA publications with variable reinfection rates (Table 2). Reinfection in these studies ranges from 0 to 25% for TKA and 0 to 65% for THA. It is difficult to draw conclusions from results of heterogeneous groups with different inclusion criteria and reconstructive strategies. Some institutions employ an aggressive radical debridement of all supporting structures around the knee and often go directly to a hinge reconstruction [27]. Others demonstrate success from using cementless rather than cemented hip stems [57].

We noted considerable variation in route of administration of antibiotics and period of treatment recorded in studies from the last 5 years [30]. The Clinical Practice Guidelines by the Infectious Diseases Society of America recommend 2–6 weeks of intravenous antimicrobial therapy with rifampicin added for *Staphylococcal* spp. followed by oral antimicrobials with rifampicin for a total of 3 months [19]. Intravenous therapy is recommended for 4–6 weeks for other causative organisms. Klouche et al. report central venous delivery of antibiotics for 42 ± 12.4 days with subsequent oral antibiotics for 51.1 ± 27.1 days [39]. Cement is an important method of antibiotic delivery for some centres but in a comparative review of single- and two-stage exchange for PJI, there was no difference in success between cementless and cemented devices [41, 72••]. Ebied et al. demonstrated 97% successful infection clearance for 33 patients treated with a single-stage exchange, and antibiotic-loaded fresh-frozen femoral head allograft manually cut into prepared bone chips [62]. Each of these results confirms that an expert microbiological advice is necessary in the peri-operative period to achieve good outcomes.

A long-term follow-up of 50 single-stage exchange cases since 1979 demonstrated cumulative 5- and 10-year probability of further revision for any reason as 4.1% (95% CI 1.1 to 15.5) and 9.6% (95% CI 3.7 to 23.9) respectively [70]. This is an update from a previous report using the same surgical protocol and inclusion criteria [64]. The best current data available is presented in a recent systematic review and meta-analysis comparing single-stage and two-stage revision for TKA PJIs [23••]. The authors sought to compare the effectiveness and determine the difference in reinfection rates and other clinical outcomes between the two strategies. From 10 single-stage and 108 two-stage articles, they showed the reinfection rate was 7.6% (95% CI 3.4–13.1) and 8.8% (95% CI 7.2–10.6) for single-stage and two-stage revisions respectively. Amongst the higher quality studies, the pooled reinfection rate was 6.4% (95% CI 2.1–12.4) and 6.1% (95% CI 3.3–9.2) respectively. There was limited data to compare clinical or functional outcomes between both treatments. We have previously demonstrated 100% successful clearance using single-stage exchange in 28 TKA PJIs with a minimum of 3-years of follow-up and 100% success with 11 THA PJIs with a minimum of 5.5 years of follow-up [35]. Although our follow-up period was relatively short, both groups demonstrated significantly better functional scores compared to patients undergoing two-stage surgeries [35, 55].

## Expansion of Inclusion Criteria for Single-Stage Exchange

There is variation in the inclusion criteria for PJI single-stage revision. Some authors are restrictive and others are liberal (Table 1). One of the oldest/longest cohorts is described with modest criteria: bacteriologically proven infection, an identified organism, available antibiotic sensitivities, and intact soft tissue cover of the knee [64, 70]. We adopt a liberal set of criteria and believe that as surgeons, infectious disease specialists, and microbiologists become familiar and experienced with protocols and techniques, the role for single-stage surgery will expand. Here, we assess if there is evidence to support expanding criteria.

Poor local bone stock is a reported contraindication for single-stage surgery (Table 3) yet a functional hip joint cannot be maintained with a pelvic discontinuity and two-stage

**Table 2** Outcome of single-stage exchange for PJI. *PJI*, prosthetic joint infection; *HHS*, Harris hip score; *OKS*, Oxford knee score; *KSS*, Knee Society Score; *VAS*, visual analogue scale; *SF-12*, short form-12; *WOMAC*, Western Ontario and McMaster Universities Osteoarthritis Index. -Denotes data not provided in article. *Denotes single-stage revision from unicompartmental knee replacement PJI to TKA

| Author | Year | PJI | Cases (*n*) | Reinfection (*n*) | Reinfection (%) | Mean follow-up (years) | Minimum follow-up or range (years) | Validated clinical score used |
|---|---|---|---|---|---|---|---|---|
| Carlsson [20] | 1978 | Hip | 77 | 17 | 22 | - | 0.5–3.5 | - |
| Hughes [43] | 1979 | Hip | 13 | 4 | 31 | - | - | HHS |
| Buchholz [21] | 1981 | Hip | 640 | 130 | 20 | 4.3 | 1.4–9 | - |
| Miley [44] | 1982 | Hip | 47 | 6 | 13 | 4 | 3 | Miley |
| Weber [45] | 1986 | Hip | 8 | 2 | 25 | 6 | 5–8 | - |
| Wroblewski [46] | 1986 | Hip | 102 | 9 | 9 | 3.2 | 2.2–6.1 | - |
| Sanzen [47] | 1988 | Hip | 102 | 25 | 25 | 71 | 2–9 | Merle D'Aubigne |
| Hope [48] | 1989 | Hip | 72 | 9 | 13 | 3.75 | 0.5–121 | - |
| Raut [49] | 1994 | Hip | 57 | 8 | 14 | 7.3 | - | Merle D'Aubigne |
| Mulcahy [50] | 1996 | Hip | 15 | 0 | 0 | 4 | 2–7 | - |
| Ure [51] | 1998 | Hip | 22 | 0 | 0 | 10.5 | - | - |
| Callaghan [52] | 1999 | Hip | 24 | 2 | 8 | 10 | - | - |
| Rudelli [53] | 2008 | Hip | 32 | 2 | 6 | 5 | - | D'Aubigne and Postel |
| Winkler [28] | 2008 | Hip | 37 | 3 | 8 | 4.4 | 2–8 | - |
| Yoo [54] | 2008 | Hip | 12 | 1 | 8 | 7.2 | 3 | HHS |
| Oussedik [55] | 2010 | Hip | 11 | 0 | 0 | 6.8 | 5.5–8.5 | HHS |
| De Man [56] | 2011 | Hip | 22 | 0 | 0 | 3.8 | 2 | HHS |
| Klouche [39] | 2012 | Hip | 38 | 0 | 0 | 2 | - | - |
| Choi [36] | 2013 | Hip | 17 | 3 | 18 | 5.1 | 1–11 | HHS; UCLA |
| Hansen [30] | 2013 | Hip | 27 | 8 | 30 | 2.25 | - | - |
| Bori [57] | 2014 | Hip | 24 | 1 | 4 | 3.6 | - | HHS |
| Jenny [58] | 2014 | Hip | 65 | 17 | 26 | 5 | 3–6 | - |
| Klatte [59] | 2014 | Hip | 6 | 0 | 0 | 2.1 | - | HHS |
| Wolf [60] | 2014 | Hip | 37 | 24 | 65 | 2 | - | - |
| Zeller [61] | 2014 | Hip | 157 | 8 | 5 | 3.4 | 2 | - |
| Ebied [62] | 2016 | Hip | 33 | 1 | 3 | 6 | - | HHS |
| Ilchman [29•] | 2016 | Hip | 39 | 0 | 0 | 6.6 | 2 | HHS |
| Freeman [63] | 1985 | Knee | 8 | 0 | 0 | 2 | 1–3.5 | - |
| Goksan [64] | 1992 | Knee | 18 | 2 | 11 | 5 | - | - |
| Scott [65] | 1993 | Knee | 10 | 3 | 30 | - | - | - |
| Silva [66] | 2002 | Knee | 37 | 4 | 11 | 5 | - | - |
| Buechel [67] | 2004 | Knee | 22 | 2 | 9 | 10 | 1.4–19 | - |
| Whiteside [68] | 2010 | Knee | 18 | 1 | 6 | 5.2 | - | KSS |
| Parkinson [34] | 2011 | Knee | 22 | 0 | 0 | 2 | - | SF-12; WOMAC |
| Singer [69] | 2012 | Knee | 63 | 3 | 5 | 3 | 2 | KSS; OKS |
| Klatte [59] | 2014 | Knee | 4 | 1 | 25 | 2.1 | - | HSS |
| Tibrewal [70] | 2014 | Knee | 50 | 1 | 2 | 10.5 | - | OKS |
| Haddad [35] | 2015 | Knee | 28 | 0 | 0 | 6.5 | 3 | KSS; VAS |
| Labruyere [71]* | 2015 | Knee | 9 | 0 | 0 | 5 | - | KSS |

strategy. Even with a contained acetabular defect, there is a 16–19% complication rate of temporary hip spacers that includes breakage, dislocation, and pelvic protrusion [73, 74]. Recent evidence suggests that single-stage major

**Table 3** Contraindications for single-stage exchange for PJI. *UCLH*, University College London Hospital; *ISDA*, Infectious Diseases Society of America

| UCLH contraindications [35] | | ENDO Klinik contraindications [41] | ISDA contraindications [19] | International consensus meeting [42] |
|---|---|---|---|---|
| Local | Significant soft tissue compromise | Failure of ≥ 2 previous one-stage procedures | No prior two-stage exchange for infection | The presence of generalised sepsis |
| | Significant bone loss precluding cemented reconstruction | Infection spreading to the neurovascular bundle | Poor soft tissue | Infections in which the bacteria is not identified |
| | Peripheral vascular disease | Unclear pre-operative bacterial specification | Difficult to treat microorganisms | Infection caused by a drug-resistant bacteria |
| Host | Immunosuppression | Non-availability of appropriate antibiotics | | The presence of a sinus tract |
| | Concurrent sepsis | High antibiotic resistance | | The presence of severe soft tissue deficiency over the joint |
| | Systemic disease | Sinus tract with unclear bacterial specification | | |
| | Reinfection | | | |
| Organism | Multiresistant organisms MRSA/MRSE | | | |
| | Polymicrobial infection | | | |
| | Unusual commensals | | | |
| | Unusual resistance profiles | | | |
| | Unidentified | | | |

acetabular reconstruction (>Paprosky 2B defects) can be performed for THA PJI [75•]. Fink et al. describe a two-stage revision that includes definitive acetabular reconstruction at the first surgery with a femoral spacer that is exchanged to a definitive cementless femoral stem after 6 weeks. Cages, porous metal components, and cup cages were implanted at the initial stage in 35 patients and 34 (97.2%; 95% CI, 85.4%–99.5%) were infection free at 24-month minimum follow-up. Allograft is not used to address bone deficiency during single-stage revision in some centres [41]. Ebied et al. recently showed good results using fresh-frozen femoral head allograft bone chips mixed with antibiotic powder in a study similar to Winkler et al from a decade ago. Both groups showed high infection control rates (97 and 92% respectively) [28, 62]. We believe that with further studies demonstrating similar results, patients with significant bony deficiency may be considered for single-stage exchange.

Poor local tissue is another common contraindication for single-stage revision surgery (Table 3). Wolf et al. recently demonstrated that local compromising factors were associated with poorer infection control in patients undergoing single-stage revision compared with two-stage revision [60]. There are unpublished reports of patients with sinuses around infected TKAs having good clearance of infection with a single-stage strategy [34]. We agree with previous expert opinion that a vacuum-assisted dressing can be temporarily used before a myocutaneous flap is brought in to cover a defect over a knee after single-stage exchange [41]. We would caution against liberally enlisting patients with very poor tissues for single-stage surgery, especially TKA PJIs.

Cementless devices are no longer contraindicated in reconstructing joints after single-stage explantation for PJI in our opinion. Cement has long been used as an antibiotic delivery agent but there is disagreement in the elution rates and concentrations released from the cement in the literature [76–78]. Some of the largest cohorts reported in the last 5 years describe high infection control rates in patients that were treated with cementless or reverse hybrid single-stage THAs [29•, 57, 61]. There is no recent data clearly showing success with cementless TKA stems but we suspect that this is due to surgeon preference in knee reconstruction [79].

Partial single-stage hip surgery has also been proposed [80]. Infection control was demonstrated in 87% of 31 patients with a minimum of 2 years of follow-up. The surgeons describe intra-operative assessment of the cemented or cementless acetabular or femoral component fixation. When the implant was considered stable, it was retained. Of the 31 patients, 22 required acetabular revision and 9 required femoral revision. Based on this small, heterogenous series, we cannot endorse a partial revision strategy but acknowledge that occasionally surgeons, in select cases, may prefer to leave well-fixed implants in situ rather than introduce further morbidity or compromise reconstruction success with extensive implant excision.

Finally, we consider whether the microbiological profile of the infective pathogen influences using a single-stage strategy.

Fungal PJIs are rare and convention is to adopt a two-stage approach for infection control [81]. Klatte et al. described one failure in ten patients undergoing hip or knee single-stage exchange surgery for fungal infection with a mean of 7 years of follow-up [59]. In another study, 11 patients (4 THA, 7 TKA) of which five had previous bacterial PJI and surgery were treated for fungal PJI using a single-stage approach [82]. Direct intra-articular injection of fluconazole was administered to patients with infected TKAs after single exchange on alternate days for an average of 18 days (12–30 days). Intra-articular fluconazole was not administered to hips. The minimum follow-up was 2 years and there were three failures: two knees and one hip. These patients went on to successful infection control with a subsequent two-stage approach. Although care should be taken with multiple-pathogen PJIs, we do not believe fungal infections are a contraindication for single-stage exchange surgery. An absolute requirement for single-stage exchange surgery for THA or TKA PJI is preoperative identification of the causative microorganism. There is no comprehensive data supporting inclusion of joint replacements infected with resistant microorganisms. Comprehensive mechanical removal of implants, foreign materials, necrotic tissue, and biofilms is the cornerstone of surgical success along with expertly led antimicrobial or antifungal therapy.

## Conclusions

There is sufficient evidence that supports using single-stage exchange to eradicate PJI, and an increasing willingness amongst surgeons to adopt this approach [83]. International consensus was agreed on the inclusion criteria for single-stage exchange, and there is emerging evidence to broaden these criteria particularly in the realm of bony deficiency [42, 75•]. There is limited evidence supporting single-stage surgery for patients with a poor soft tissue envelope. Infection control non-inferiority have been shown with single-stage revision but with fewer datasets compared to two-stage revision [23••, 33, 83, 84]. Better data is required. In the last 5 years, there are 16 articles reporting single-stage revision and 19 reviews or opinion pieces in the same period on the topic. Clearly, there is an interest in the technique and it is hoped that well-designed, prospective randomised trials that are currently recruiting will offer better evidence for single- versus two-stage exchange revision [85]. It is important that surgeons adopting the single-stage approach execute the procedure as we and other authors have described [26, 86]. Comprehensive mechanical debridement provides the platform for antimicrobial agents to work. We do not envisage abandonment of the two-stage strategy, but instead we advocate that surgeons consider whether their patient with a chronic PJI is suitable for single-stage exchange surgery.

## Compliance with Ethical Standards

**Conflict of Interest** All authors declare that they have no conflicts of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance


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