Revision total hip arthroplasty for periprosthetic fracture: epidemiology, outcomes, and factors associated with success

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Abstract: The aging population and the increasing number of patients with primary total hip arthroplasties (THA) has equated to an increased incidence of periprosthetic fractures (PPF) of the hip. These injuries are a significant source of patient morbidity and mortality, placing a financial burden on healthcare systems worldwide. As the volume of PPF is expected to along with the growing volume of primary and revision THA, it is important to understand the outcomes and factors associated with treatment success. The choice of procedure is in large part guided by the help of the Vancouver Classification system, which is a valid and reproducible system that classifies fractures based on several factors including site of fracture, implant stability and bone stock. PPFs account for approximately 18% of revision THA (rTHA) procedures. rTHA for PPFs is commonly indicated in Vancouver B2 and B3 fractures, to bypass a lack of metaphyseal support with diaphyseal fixation. Such revisions are technically challenging and typically require urgent treatment, with inherent difficulties in patient optimization, leading to a notable rate of post-operative complications, re-revision and mortality. This article reviews epidemiology, health economics and risk factors for PPFs. It additionally reviews outcomes associated with rTHA for PPFs including peri-operative complications, indications for re-operation, rates of re-operation and rates of mortality. Finally, it aims to identify evidence-based factors that have been associated with successful management including modifiable patient-related factors, uncemented *vs.* cemented stems, stem design (porous coated stems *vs.* fluted tapered stems), modularity, dislocation and its impact on outcomes following rTHA and strategies for managing bone loss.

Keywords: Hip; revision total hip arthroplasty (rTHA); trauma; periprosthetic hip fracture

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Introduction

Total hip arthroplasty (THA) is among the five most commonly performed surgical procedures annually in North America (1,2). In light of the growing population and aging demographics, the incidence of primary and revision THA (rTHA) is projected to grow by 174% and 137%, respectively, between 2005 and 2030 (3). Despite improvements in surgical technique and implant design, post-operative re-operations/revisions continue to be a significant complication following THA. Using the National Inpatient Sample (NIS) database, Schwartz *et al.* (4) showed that periprosthetic fractures (PPFs) account for 18% of revision THA procedures. Moreover, they reported that the largest growth in causes for THA failure and indication for revision was due to PPF, with a 75% increase from 2002–2014.

The incidence of PPFs following primary THA has been reported from several registries. Cook *et al.* (5) reviewed 6,458 primary cemented THAs and reported an incidence of 0.8% and 3.5% for PPF at 5- and 10-year, respectively.

Similarly, Meek *et al.* (6) analyzed 52,136 primary THAs and 8,726 revision THAs from the Scottish National Database between 1997–2008. The authors reported an incidence of PPF of 0.9% and 4.2%, after primary and revision surgery, respectively at 5-year follow-up and incidence of PPF of 1.7% and 6.2% after primary and revision THA, respectively, at 10 years postoperative. Other analyses corroborate the greater risk of PPF after revision surgery (7). Finally, in a review of over 5,400 revision THAs from the Mayo Clinic Total Joint Registry, Abdel *et al.* (8) reported the cumulative probability of PPF was 1.9% at 1 year, 3.8% at 5 years, 6.4% at 10 years and 11.4% at 20 years.

Therefore, as the volume of PPF is expected to rise in-step with the growing volume of primary and revision THA, it is important to understand the outcomes and factors associated with treatment success (7,9).

Health economics

PPFs have important financial ramifications on health care systems (10,11). In fact, cost of rTHA in the United States for an indication of PPF or implant fracture (median: $27,596) has been shown to be significantly more expensive than for the indications of wear/loosening (median: $21,176) or dislocation/instability (median: $16,891) (12). These findings were corroborated by Shichman *et al.* (13) who similarly reported patients undergoing rTHA for PPF were associated with the highest length of stay (LOS), total and direct costs compared to other indications for rTHA. These higher costs may be explained, in-part, by the long operative times and longer length of hospital stay (13,14). Similarly, in Canada, the cost of rTHA for an indication of PPF (mean: $33,500) is higher than for aseptic indications (mean: $19,500) or prosthetic joint infection (mean: $30,600) and has increased 400% from 2009–2018 (15). Jain *et al.* (16) performed a cost analysis of treating PPFs and noted the highest costs to be associated with ward stay, operating room utilization, and overhead costs. The authors advocated for several methods to improve cost-effectiveness including enhanced recovery programs to reduce LOS, and dual surgeon operating for more complex cases by way of improving surgical efficiency and reducing operating time, while also reducing the risk of complications.

Risk factors

The rise in the incidence of PPF represents the summation of several patient factors including increasing patient activity and longevity. Such a rise, results in a longer utilization of THA components, ultimately leading to an increased fracture risk (17,18). Many patient and surgical factors have been proposed over the years to influence the risk of sustaining a post-operative PPF following THA (*Table 1*). Much of the existing literature on surgical risk factors for PPFs focuses on cemented *vs.* uncemented primary THA, surgical approach as well as stem design. There is an abundance of literature to suggest that uncemented stems are associated with a higher risk of PPF, compared to cemented stems (19,24-26,31). The results regarding the effect of surgical approach on PPFs are mixed. While previous studies have suggested that direct anterior approach (DAA) predisposes patients to post-operative PPFs (32-34), the results from Sershon *et al.* (27) contradict these findings, noting surgical approach to have minimal effect on PPF risk. The authors suggest stem choice may have a greater influence on the risk of PPF. Recent studies have suggested certain stem factors to be associated with a higher risk of PPF. Some of these factors include collarless compared to collared, single-taper and double-taper compared to compaction collared, and collarless taper slip compared to composite beam stems (27,35,36).

Principles of PPF treatment—when is revision arthroplasty recommended?

The two most common surgical approaches used in the management of PPFs are retaining the femoral component with open reduction internal fixation (ORIF) or performing a revision THA whereby the femoral component is exchanged and the fracture is commonly reduced with cerclage cables. The choice of procedure is in large part determined by the Vancouver Classification, which is a reliable and valid system, that offers a reproducible description of the site of fracture, implant stability and bone stock (20).

The Vancouver classification system helps guide PPF management based on these factors. There is variability in treatment for PPFs. In general, Vancouver AG and AL fractures are stable and managed non-operatively with protected weight-bearing. Operative management is occasionally indicated for displacement of greater trochanter >2 cm in AG fractures (21,22). Vancouver B patterns have been reported as the most common PPF configuration (8,23,28). In Vancouver B1 fractures where the implant is well-fixed, treatment includes ORIF with a plate or cerclage wires (29). Parvizi *et al.* (30) proposed a protocol,

Table 1 Factors that have been suggested to increase the risk of PPFs

Factors	References
Patient factors	
Age	(5,6,19-23)
Female gender	(21,22,24-29)
Osteoporosis	(19,20,23)
BMI <25 kg/m^2	(20,27)
Low energy trauma	(23)
Presence of osteolysis	(23)
Canal flare index >3.17	(30)
Rheumatoid arthritis	(19,21,23,25)
Absence of contralateral OA	(22)
Presence of contralateral THA in place	(6)
Dorr type C femora (compared to type B)	(28)
Low household income	(29)
Malnutrition	(29)
Hemiparesis/hemiplegia	(29)
Surgical factors	
Uncemented femoral stem	(3,8,9,12,15)
Single-wedge and double wedge (fit-and-fill) femoral implants (compared with fully coated tapered/rounded stems)	(16)
Collarless, polished, tapered cemented stem (compared to composite beam)	(4,16,17)
Collarless component (compared to collared)	(8)
Straight stem (compared to short stem)	(10)
Greater stem canal fill for DAA	(18)
Revision THA	(3,5,9,24)
Technical errors (cortical perforation, poor cementation technique)	(3,25)
Rapid and forceful femoral preparation and implantation	(26)

PPFs, periprosthetic fractures; BMI, body mass index; OA, osteoarthritis; THA, total hip arthroplasty; DAA, direct anterior approach.

recommending femoral component revision to a stem with diaphyseal fixation for Vancouver B2 and B3 fractures, to bypass the lack of metaphyseal support. Data from the Swedish National Hip Arthroplasty Register demonstrated Vancouver B2 patterns to account for 53% of PPFs (37). The gold standard for treatment for B2 and B3 fractures is femoral component revision to a stem with diaphyseal fixation and sometimes ORIF. A previous systematic review noted 298/343 (86.8%) B2 fractures (51.3% uncemented stems, 27.6% cemented stems, 21.1% unspecified) were treated with revision surgery, while 160/167 (95.8%) B3 fractures (53.9% uncemented stems, 16.8% cemented stems, 12.6% unspecified) were treated with revision (38).

Finally, the standard of care of Vancouver C fractures includes ORIF with potential supplementation with strut allograft (39). The Vancouver classification has shown better ability to guide treatment in uncemented rather than cemented stems around collarless, polished, tapered design (40).

Outcomes following revision THA for PPF

Outcome metrics that are used to measure treatment outcome following surgical treatment of PPF include perioperative complications, revision surgery, and mortality (41,42).

Perioperative complications

Many complications have been documented following revision THA for PPFs. In a systematic review and meta-analysis that reported on patients managed for Vancouver B2 and B3 PPFs, Haider *et al.* (41) found a complication rate of 17.8% at a mean 3.5-year follow-up in 960 rTHAs. Re-fracture (2.1%), loosening (3.8%) and infection (4%) accounted for most complications in their study. Similarly, in a systematic review and meta-analysis that reported on outcomes for patients managed for Vancouver B2 fractures, Lewis *et al.* (42) reported a complication rate of 18%. The most common complications reported in their rTHA cohort included dislocation (4.8%), infection (3.4%), aseptic loosening + subsidence (3%), and re-fracture (2.3%).

In an analysis of 1,422 aseptic revision THAs from the American College of Surgeons National Quality Improvement Program (ACS–NSQIP), Hevesi *et al.* (12) reported a 30-day complication rate of 20.7% for PPFs, which was higher than rTHA for an indication of dislocation/instability (9.0%) but similar to rTHA for an indication of wear/loosening (17.6%). The authors postulate that such a large complication rate may stem from the fact that rTHA for PPFs is on a relatively urgent basis, which results in a lot of patients undergoing surgery that have not been optimized for surgery. Moreover, the fracture

Table 2 Summary of systematic reviews that reported on re-revision following rTHA for PPFs

Study	Number of PPFs treated with rTHA	Re-operation rate (%)	Follow-up
Haider *et al.* (52)	1,769	13.5	3.7 years
Lewis *et al.* (53)	1,280	10.5	37 months
Kahn *et al.* (51)	343 (Vancouver B2); 160 (Vancouver B3)	12.4 (Vancouver B2); 14.4 (Vancouver B3)	32–74 months

rTHA, revision total hip arthroplasty; PPFs, periprosthetic fractures.

population in their study demonstrated a higher age and comorbidities compared to other cohorts in their study. Notable 30-day complications for rTHA for 150 PPFs reported in their study include wound complications and infection (superficial or deep) (12.7%), deep vein thrombosis (1.3%), pulmonary embolism (0.7%), neurologic (sciatic palsy) (1.3%), dislocation (6.0%), re-fracture (10.0%).

Mortality

Several studies have reported on mortality following PPFs as an endpoint of relevance (43-46). Many studies that report on mortality following surgical treatment for PPFs do not differentiate between outcomes for patients managed with ORIF *vs.* revision THA surgeries. A meta-analysis of 4,841 patients from 35 studies with PPF (regardless of modality treatment used) reported a pooled 30-day mortality of 3.3%, 90-day mortality of 4.8% and 1-year mortality of 13.4% (47). Risk factors associated with post-operative mortality include age above 85 years old and pre-PPF functional status (48).

Mortality following a PPF is significantly higher than mortality for patients undergoing primary THA (43,49). This rate has previously been suggested to plateau after 5 years (50). Fewer studies have reported on mortality following rTHA for PPF. Khan *et al.* (43) analyzed 74,223 revision THAs and reported a mortality rate following revision for PPF of 9% at 90 days, 21% at one year, 60% at 5 years in the highest risk group (male, ≥75 years old, ASA ≥3), and 0.6%, 1.4%, and 5.5%, respectively in the lowest risk group (female, <75 years old, ASA ≤2). In comparison, hip fracture mortality from 14,294 patients 60 years of age or older from the Kaiser Permanente Hip Fracture Registry reported a mortality of 6% at 30-days, 11% at 90 days and 21% after 1 year (51).

In their systematic review and meta-analysis that compared ORIF to rTHA for Vancouver B2 and B3 fractures, Haider *et al.* (41) reported a mortality rate of 17% from 584 patients that underwent rTHA at a mean 2.8-year follow-up. The authors additionally noted that mortality did not differ between the 2 cohorts.

Re-operation

Several systematic reviews have reported on the rate of re-operation following rTHA for PPFs, which has been estimated to range from approximately 11–14% following rTHA (*Table 2*). Cited indications for re-operation include refracture (21%), infection (7%), subsidence (14%), aseptic loosening (9%), nonunion (9%), dislocation (9%), wound infection/hematoma (9%) (38). These are discussed in detail in the sections that follow.

Patient reported outcomes and psychological outcomes

Few studies have discussed patient reported outcomes (functional and psychological) following rTHA for a PPF (54,55). The findings of Islam *et al.* (52) suggest poor physical function and psychological well-being following rTHA. In an analysis of 232 rTHAs from the New Zealand Registry, Young *et al.* (46) found that patients that underwent rTHA for PPFs have poorer functional outcomes, compared to patients undergoing rTHA for aseptic loosening. The literature for such outcomes is scarce and further high-quality investigation is required.

Factors associated with treatment success

Patient-related factors

Much of the existing literature has focused on surgical techniques to improve outcomes in PPFs. In the hip fracture population, many factors have been proposed to influence mortality including age, ethnicity, sex, medical comorbidities, socioeconomic factors (low income, low education level, living in a healthcare facility) and health care factors (hip fracture volume) (53,56,57). However, modifiable patient-related factors and methods to optimize patients undergoing rTHA for PPF are decidedly lacking. Gibbs *et al.* (58) found dislocation (OR =5.03), hospital-acquired pneumonia (OR =4.43), American Society of Anesthesiologists (ASA) physical status of 3 or 4 (OR =3.98) and pre-operative anemia (male hemoglobin <130 g/L, female hemoglobin <120 g/L) (OR =3.46) to be potentially modifiable risk factors for mortality following rTHA for PPF. Additionally, they recommend implementing standardized programs and multi-disciplinary involvement to reduce the risk of pneumonia. A geriatric multidisciplinary clinical pathway team has been shown to reduce length of stay and improve mortality in patients with hip fractures (59). Cassidy *et al.* (60) showed that implementing a standardized post-operative care program (I COUGH) emphasizing incentive spirometry, cough and deep breathing, oral care, getting out of bed 3 times daily and head of bead elevation reduced the incidence of post-operative pneumonia in general and vascular surgery patients. Such methods may additionally benefit patients in the PPF population undergoing rTHA. Further high-quality investigation is required.

Finally, early weight-bearing is an aspect of post-operative care that may improve patient outcomes. Compared to late weight-bearing, immediate weight-bearing has been suggested to decrease mortality in the PPF population (61,62). Similar findings have been noted in the hip fracture population (63,64). Efforts to improve rapid recovery and accelerate weight-bearing for PPF patients are warranted.

Cemented vs. uncemented revision THA

Revision of the femoral component with a long porous-coated cementless stem and fixation of the fracture fragment(s) is typically the most favorable surgical strategy for the treatment of Vancouver B2 and B3 PPFs (38,42,65,66). Uncemented implants are easier to revise and do not carry a risk of cement extrusion into the fracture site or interference on fracture healing, leading to non-union (67). Uncemented, extensive coated prostheses have been shown to perform better than cemented stems for revision in type B (B1-B3) PPFs (45). Disadvantages to uncemented long stems include limited weight-bearing in the immediate post-operative period, stress shielding and stem subsidence (68). Stem length has the potential to influence the outcomes of revision THA, however little is known on its impact in the PPF population. Stem diameter and stiffness, factors which are influenced by length and curvature, have previously been shown to influence bone remodeling patterns (69). Tsiridis *et al.* (70) noted that Vancouver B3 fractures that were treated with a cemented revision with impaction revision were 5 times more likely to unite than those treated by impaction grafting with a short stem. Further detailed investigation is required.

For PPFs around a primary cemented femoral stem, additional considerations are necessary. Vancouver A, B and C fractures have been shown to occur equally in cemented and uncemented stems (71). In general for Vancouver type A and C fractures, the principles of management are the same as uncemented stems (72). When managing a Vancouver B PPF around a cemented implant, a surgeon can decide to remove the cement and place a new cemented or cementless stem (*Figure 1*). In many cases, revising a stem necessitates the difficulty of removing an existing cement mantle, which adds time to the procedure and carries the added risk of iatrogenic fragmentation of bone. An alternative to this includes a cement-in-cement technique, whereby the cement at the cement-bone interface is retained. Such a technique is indicated for non- extensively communited fractures and has the added benefit of reducing intraoperative time and blood loss in patients who are not candidates for long procedures (73). Despite concern that cement extrusion could theoretically inhibit fracture healing, the results of several studies appear to contradict such a dogma. Klasan *et al.* (74) reported comparable surgical complications, patient survivorship (62.5% in-cement, 69.8% uncemented, P=0.094) and implant survivorship (93.5% in-cement, 94.4% uncemented, P=0.946) at 5-year follow-up between the two techniques following rTHA for PPF. Other studies corroborate the effectiveness of the following technique for PPFs (75,76).

Finally, in cases where the bone cement-interface is intact and the fracture is anatomically reducible, a surgeon may also manage Vancouver B fractures with fixation as opposed to rTHA, which has the benefit of reduced need for blood transfusion and lower risk of revision arthroplasty (77).

Stem design

During revision arthroplasty, a surgeon is challenged with deficient proximal bone and thus relies on the amount of distal bone to provide axial and rotational stability (78). In the past, cementless fully porous coated stems were favored, however issues with distal fixation, subsidence, proximal stress shielding, and thigh pain were factors cited to limit their routine use (79,80). Furthermore, these implants are limited in cases with proximal femoral bone

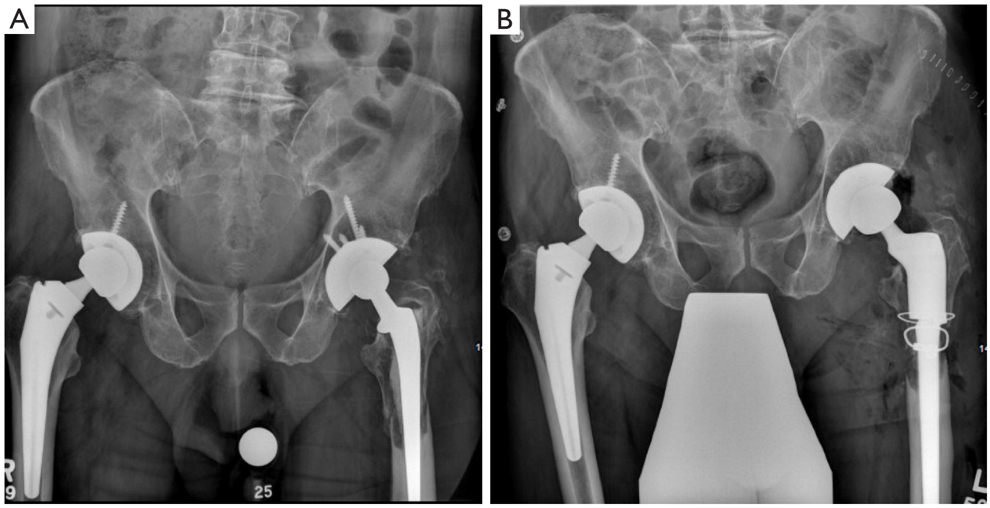

Figure 1 Management of a PPF around a cemented femoral implant. (A) Example of patient with left sided Vancouver B2 peri-prosthetic fracture around a cemented femoral stem; (B) during rTHA, the cement mantle was removed and revision to a long-stemmed cementless Arcos femoral component was performed, with cementation of a liner and addition of 2 wires for fixation. PPF, periprosthetic fractures; rTHA, revision total hip arthroplasty.

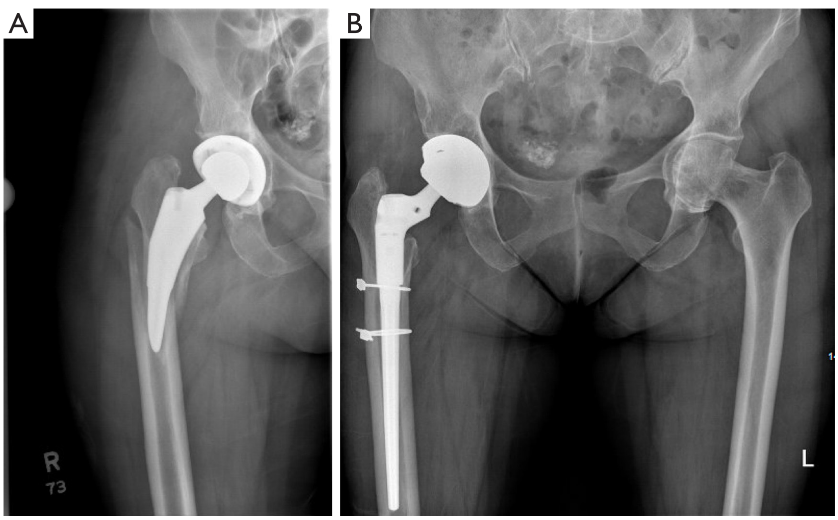

Figure 2 rTHA for Vancouver B2 and B3 PPFs with a fluted tapered stem. (A) Example of Vancouver B2 peri-prosthetic fracture from index primary THA; (B) treated with rTHA with Arcos modular fluted, tapered stem, and ORIF with 3 Dall Miles Cables. rTHA, revision total hip arthroplasty; PPF, periprosthetic fractures; ORIF, open reduction internal fixation.

loss. Fluted tapered stems have increased in popularity and emerged as the mainstay of treatment when performing revision arthroplasty for Vancouver B2 and B3 fractures and have demonstrated excellent short-, mid- and long-term survivorship (*Figure 2*) (81-85). Compared to porous coated stems, titanium fluted tapered stems have fewer intra-operative and post-operative complications and are associated with improved hip function, pain, stiffness and satisfaction scores (29,86).

An important feature is their ability to achieve good outcomes in the context of proximal bone loss. Proximal bone stock has been shown to increase when using a titanium fluted stem (87,88). Moreover, these implants have the added benefit of allowing for immediate full weight-bearing (84). Distal fixation is advantageous as the stem bridges the fracture, while the point of fixation is remote to

Table 3 Outcomes for modular fluted tapered stems for rTHA for PPFs

Study	Number of cases	Mean follow-up (years)	Survivorship free of revision	Union rate
Hannon *et al.* (94)	171 (109 B2; 62 B3)	5	10-year cumulative incidence: 90%	99%
Munegato *et al.* (95)	25 (21 B2; 4 B3)	2.43	88%	96%
van Laarhoven *et al.* (96)	87 (5 B1; 70 B2; 12 B3)	2.9	100%	94.3%
Munro *et al.* (97)	46 (30 B2; 16 B3)	4.5	95.7%	97.8%
Parry *et al.* (98)	61	4.5	1-year: 93%; 2-year: 93%; 5-year: 93%	93%
da Assunção *et al.* (99)	37 (31 B2; 6 B3)	2.9	100%	100%
Otero *et al.* (100)	129 (41 B2; 6 B3)	3.8	94.6%	Not recorded
Berry *et al.* (101)	8 B3	1.5	100%	100%

rTHA, revision total hip arthroplasty; PPFs, periprosthetic fractures.

the fracture site, allowing for the stability of the implant to not be impacted by fracture fixation (66). It has previously been recommended that the length of the femoral component bypass the fracture by a minimum of 2 cortical diameters (45,89).

Modularity

Modularity has been a topic of controversy in recent years. Modular stems are a valuable treatment option during revision arthroplasty, by allowing the surgeon to adjust length, version, and offset after obtaining stability distally (90).

Many surgeons currently use modular stems due to their ability to independently control stem and body size. However, modular stems are not without their limitations which include including fatigue failure and corrosion at the modular junction (91-93). Cited risk factors for fatigue failure and fracture at the modular junction include increased body weight, osteolysis, loosening, reduced pre-operative bone stock and implant under sizing (92). Despite the reported risk factors, several studies demonstrate good survivorship and fracture union rate when used in Vancouver B2 and B3 fractures. There is very good evidence to support modular stems providing good clinical outcomes and implant survivorship for revision THA for PPFs (*Table 3*).

Monoblock stems are an alternative option to modular stems and have good survivorship outcomes reported (69,92,100,102). Advantages of monoblock stems include the absence of complications at the modular junction, less stress shielding and reduced costs compared to modular stems (69). The primary disadvantage to these implants is the reduced intra-operative flexibility to modify version and femoral offset, a feature which is important particularly useful during complex femoral revisions. Monoblock stems are thus a good option for experienced surgeons in uncomplicated cases, that would like to minimize TJA costs. When compared in the rTHA population, modular and non-modular tapered fluted stems have both shown to demonstrate comparable survivorship and satisfactory mid-term outcomes (102,103). Modular stems, have been reported to have a higher rate of intraoperative fracture however lower rates of post-operative subsidence and length discrepancy compared to non-modular stems (102,103). The findings by Chatziagorou *et al.* (104) suggest similar outcomes between modular and monoblock revision components for Vancouver B fractures. There is a paucity of high-quality evidence that directly compares outcomes between monoblock to modular stem use in the management of PPFs.

Dislocation

Dislocation following revision arthroplasty for a PPF is a feared complication with an estimated incidence 5–16% (82,83,94,96,97). Dislocation has been proposed to influence outcomes particularly following revision for PPFs. Gibbs *et al.* (58) reported a dislocation rate of 10% and noted patients who dislocated after revision THA for PPF were 5-times more likely to die in post-operative year 1 (105,106).

Bearings are an essential consideration for mitigating the risk of dislocation following rTHA for PPFs. Dual mobility liners are an effective method to decrease the risk of post-operative instability after rTHA (*Figure 3*) (107,108). These may be cemented into a well-fixed acetabular shell at the time of revision (109). Cited concerns regarding dual mobility implants include intra-prosthetic dislocation between the

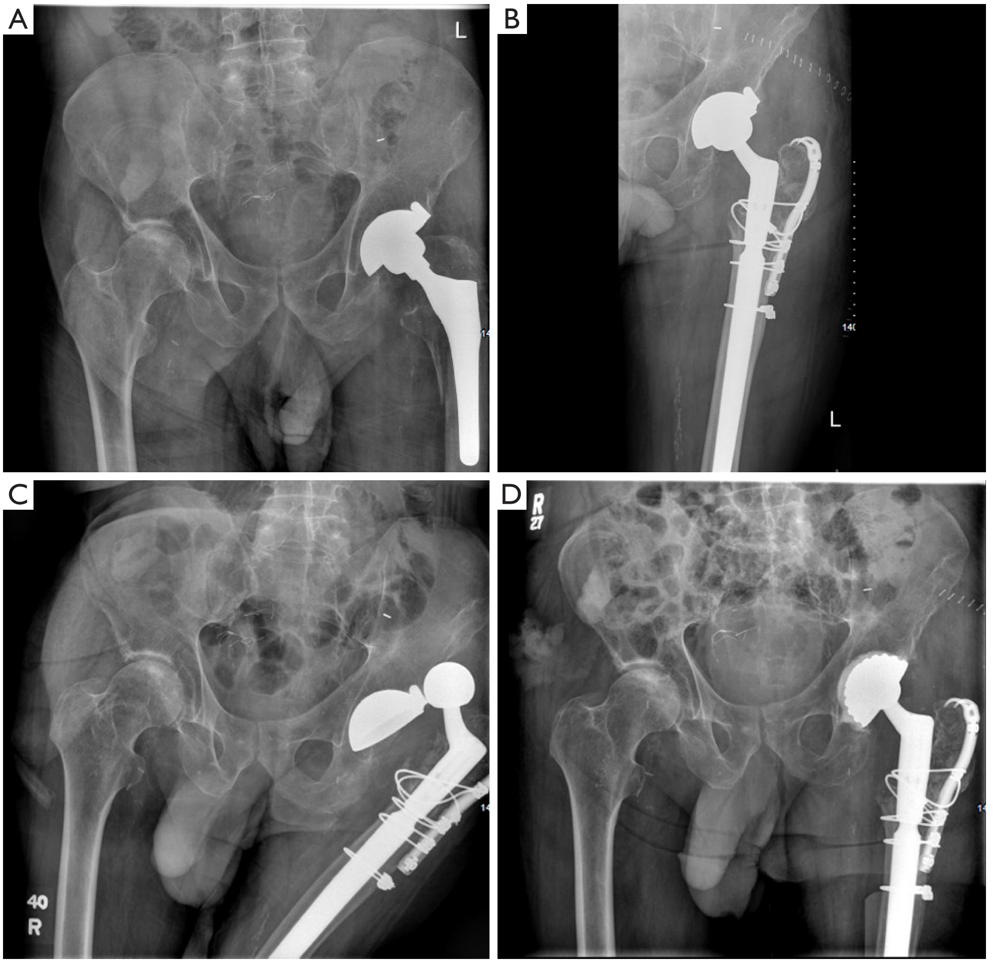

Figure 3 Management of instability following rTHA for PPFs. (A) An example of a Vancouver B2 PPF; (B) treated with rTHA with Stryker Modular Restoration Stem and supplemental fixation with Accord trochanteric fixation plate and multiple cerclage cables; (C) post-operative posterosuperior dislocation of the femoral head from the acetabular component; (D) dislocated rTHA treated with rTHA to Medacta Dual Mobility Acetabular Cup with Medacta Versafit dual mobility polyethylene liner. PPFs, periprosthetic fractures; rTHA, revision total hip arthroplasty.

liner and the femoral head, likely necessitating an open procedure and potential accelerated wear imparted by two articulating surfaces (108,110). Despite these concerns, while not many studies have focused on dual mobility liners for PPFs in rTHA, dual mobility constructs have overall provided good outcomes in rTHA and have particularly been useful for mitigating the risk of dislocation (111). Hartzler *et al.* (112) reported compared with large femoral heads, dual mobility constructs were associated with reduced rates of dislocation, re-revision and reoperation for rTHA.

Subsidence has additionally been proposed to be a factor increasing the risk of dislocation (113). Risk factors identified to be associated with subsidence include patient weight greater than 80 kg, femoral stem press-fit distance less than 2 cm, Dorr C type femora and strut grafting (indicating underlying bone loss) (95,98). Tangsataporn *et al.* (95) emphasized aggressive reaming and intra-operative radiographs to ensure good cortical contact of the stem, which should be greater than 2 cm in length. There is a tendency to undersize the stem due to risk of creating an intra-operative iatrogenic fracture. This is corroborated by the findings of Patel *et al.* (99) who noted all stems that underwent revision due to subsidence in their series were undersized, which emphasizes the important of a learning curve, poor intra-operative judgment or poor technique. Hospital volume and nonteaching hospitals have similarly been linked to higher rates of adverse outcomes, including PPFs are primary THA (101,114). When possible, rTHA for PPFs should be performed by arthroplasty surgeons performing high volume revision work.

Bone loss

When managing Vancouver B3 fractures with deficient bone stock, surgeons are challenged with achieving both implant and fracture stability. It is important to recognize that bone loss encountered during the time of surgery is likely greater than initially thought on pre-operative radiographs (115). In the case of PPF with inadequate bone stock, treatment should be with a long-stemmed femoral component with bone augmentation with extra and intramedullary fixation in the form of impaction grafting or biological strut grafts (116). Another option includes a proximal femoral replacement in cases where the proximal femur cannot be reconstructed (117).

Impaction bone grafting (IBG) can be used when the bone defect is mild or moderate, however severe bone loss may predispose patients to subsidence and fractures (118). IBG has been shown to reliably restore bone stock in revision THA with a good 20-year survivorship (118-121). This method however is technically challenging. Diaz-Dilernia *et al.* (121) reported greater overall complications, infections, and implant failures for Vancouver B3 fractures treated with IBG and a cemented stem, compared to patients treated with a distally fixed uncemented modular stem. Conversely, Tsiridis *et al.* (70) found that in 106 Vancouver B2 and B3 fractures, long stem cemented revision with impaction bone grafting was associated with higher union rates compared to long stem cemented revision without IBG (OR =4.07). When managing severe bone loss with PPF, the addition of cortical strut allograft offers the ability to reconstitute bone stock (122,123). Such a technique remains a topic of contention due to its mixed findings on fracture healing and concerns over soft tissue stripping (83,124-126). Other factors that have been cited to mitigate the risk of non-union during revision THA include careful handling of soft tissues to maintain osseous vascularity and avoiding cement extrusion into the fracture site (45). Shah *et al.* (125) recommended reducing spiral and oblique fractures with cables, and the use of a circumferential wire mesh for transverse fractures, that spans two cortical diameters above and below the fracture site.

Proximal femoral replacement is an additional option when proximal support is required or in the setting of a pathologic fracture. Such a technique offers stable and predictable outcomes for patients with severe bone loss undergoing rTHA (127). Grammatopoulos *et al.* (128) reviewed 79 patients treated with a proximal femoral replacement for a non-neoplastic indication. The authors reported a 5-year survival of 87% and a mean Oxford Hip Score (OHS) of 28. Mega prostheses have the advantage of providing initial construct stability that allows early rehabilitation and mobilization. Due to lack of viable tissue for reattachment, their reliance on intact diaphyseal bone stock for fixation, and the limited options that exist in the event a subsequent revision is required, these implants are rarely used. Patients to consider such implants include those with limited life expectancy and intact diaphyseal bone where early weightbearing is essential (129). The current literature on proximal femoral replacements with mega prostheses for PPFs is scarce (117,130).

Conclusions

PPFs are increasing in incidence and have the potential to create notable morbidity and mortality in the arthroplasty population. Vancouver B2 and B3 fractures are associated with a loose stem and warrant revision THA. Revision THA for PPFs is a technically demanding procedure. It is important for surgeons to be aware of factors that are associated with fracture union and implant stability to maximize outcomes and to provide patients with a return to their pre-injury functional status.

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Footnote

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