EOR | volume 5 | september 2020
DOI: 10.1302/2058-5241.5.200003
www.efortopenreviews.org

EFORT open reviews

Postoperative periprosthetic femoral fracture around total hip replacements: current concepts and clinical outcomes

Ashoklal Ramavath[1]
Jonathan N. Lamb[1,2]
Jeya Palan[1]
Hemant G. Pandit[1,2]
Sameer Jain[1]

- The rising incidence of postoperative periprosthetic femoral fracture (PFF) presents a significant clinical and economic burden.
- A detailed understanding of risk factors is required in order to guide preventative strategies.
- Different femoral stems have unique characteristics and management strategies must be tailored appropriately.
- Consensus regarding treatment of PFFs around well-fixed stems is lacking, but revision surgery may provide more predictable outcomes for unstable fracture patterns and fractures around polished taper-slip stems.
- Future research should focus on implant-related risk factors, treatment of concurrent metabolic bone disease and the use of large endoprostheses.

Keywords: current concepts; periprosthetic fracture; risk factors; surgical treatment; total hip replacement

Cite this article: EFORT Open Rev 2020;5:558-567.
DOI: 10.1302/2058-5241.5.200003

Introduction

Total hip replacement (THR) consistently provides excellent pain relief and an improved quality of life for patients with severe arthritis.[1] Increasing numbers of THRs are being performed annually[2] but with this trend comes the inevitable increase in complications, such as periprosthetic femoral fracture (PFF). The rate of PFF is 3.5% following primary THR but this will rise with a predicted incidence of 4.6% per decade over the next 30 years.[3,4] The UK National Joint Registry identifies PFF as the third most common cause of revision, and since 2013 revision for PFF has nearly doubled.[5] The treatment of PFF is multifaceted and requires expertise in both fracture fixation and revision arthroplasty. Many patients are elderly with significant comorbidities and surgery is associated with high complication rates.[6,7] Given the increasing burden and complexity associated with PFFs, this article aims to present current concepts involved with modern management strategies.

Risk factors

PFF is usually due to a low-energy fall in elderly patients but may occur spontaneously due to implant loosening, severe osteolysis or a stress riser from an adjacent implant. An understanding of modifiable risk factors for PFF is crucial when determining preventative strategies during THR.

Patient-related risk factors

Clinical evidence suggests that risk increases with age[8,9] but this effect is not consistently demonstrated when accounting for confounding factors.[10,11] The relationship between gender and PFF risk is also inconsistently reported, with several studies showing a greater risk in women,[12] men[13,14] or no difference.[15,16] However, an association exists with stem fixation as men are at a higher risk of PFF with cemented stems and women at a higher risk with cementless stems.[8] The effect of increasing age is more pronounced in women which is likely the result of menopause-related osteoporosis.[8] Increasing American Society of Anaesthetists grade has been associated with increased PFF risk[12] but with a variable relationship.[9,14] An increased rate of medical comorbidities such as osteoporosis, heart disease and peptic ulcer disease[13,17] is reported in cohort studies, but obesity is not a useful predictor of risk.[11,12,17]

Fig. 1 Plain radiographs demonstrating collarless non-grit blasted cementless stems. (a) Triple-tapered stem. (b) Blade-type stem.

Dorr type C femurs[18] have been associated with an increased PFF risk when using cementless stems.[11] Indications for primary THR other than osteoarthritis are associated with an increased PFF risk,[13,15] with the greatest risk in avascular necrosis and femoral neck fracture.[8,17]

Surgical risk factors

PFF risk may be greater with minimally invasive approaches, including the direct anterior approach,[18-21] but there are confounding factors with stem design and patient-related factors. Intraoperative fracture increases the risk of early revision surgery for subsequent postoperative fracture[2,17] and this may be related to poor bone quality or failure to identify the intraoperative fracture. Stem malalignment does not alter risk when the stem is well-fixed[11] but loose stems with varus subsidence may impinge on the lateral cortex and lead to a stress-riser effect.[22] Cementless stems are consistently associated with a higher PFF risk than cemented stems due to impaction forces required for press-fit fixation, particularly as the majority of cementless stem fractures occur within the first six months.[8,12,23] PFF risk is not uniform for all cemented stems, with composite-beam (CB) stems associated with a lower risk than modern polished taper-slip (PTS) designs.[14,24-26] Cementless stem design also appears to have a significant effect with the greatest risk presented with collarless, blade-type, non-grit blasted and triple-tapered stems (Fig. 1).[24,27]

Prevention

Vitamin D and calcium supplementation improves bone mineral density and may show a small protective benefit against hip fracture, but this effect has not been studied following THR.[28] Bisphosphonates are used to treat osteoporosis and whilst they may reduce periprosthetic bone loss following THR, they can lead to atypical PFFs which have higher rates of reoperation and infection.[29,30] Parathyroid hormone can increase periprosthetic bone mineral density[31] and it has been used in the non-operative management of undisplaced and ununited PFFs.[32,33] An evidence-based screening programme for high-risk patients may help ease the increasing burden of PFF, particularly for those with undiagnosed metabolic bone disorders.

Clinical evaluation

A detailed clinical assessment including mechanism of injury, functional status and medical history is essential. Pain prior to injury may suggest implant loosening, osteolysis, bisphosphonate use or concurrent infection.[34,35] Laboratory work-up must include a full blood count, urea and electrolyte screen, clotting and blood group screening. Radiographs of the hip and entire femur in two orthogonal planes must be performed to assess implant and fracture-related characteristics. These must be compared to earlier radiographs to evaluate loosening or osteolysis. Acetabular components may also be loose in a significant number of cases and may require revision.[36] It is challenging to determine implant loosening with plain radiographs[37] and computed tomography (CT) scans can be useful in identifying debonding, cement mantle disruption and osteolysis. Operation notes from the original primary THR are helpful to determine prior surgical approach and implant details.

Classification

The Vancouver classification system has recently been expanded into the Unified Classification System (Table 1) which is applicable to all major joints and has substantial reliability and validity.[38,39] This system guides surgical treatment based on stem stability and bone loss. The original Vancouver classification was validated using older types of cemented stem and is less reliable for cementless stems.[40] It also does not account for patient-related factors such as a medical comorbidity, functional requirements or patient expectations and serves only as a broad guide.

Table 1. Unified Classification System for periprosthetic fractures.

Type	Description	Example
A	Involving apophysis e.g. avulsion	Greater or lesser trochanter
B	Directly adjacent to implant	Femoral shaft fracture around stem
B1	Well-fixed implant	
B2	Loose implant and good bone stock	
B3	Loose implant and poor bone stock	
C	Distant to implant but within same bone	Distal femur fracture below stem
D	Interprosthetic – between two joint replacements at either end of long bone	Femoral shaft fracture between a hip and knee replacement
E	Involves two bones supporting one joint replacement	Combined acetabular and femur fracture around THR
F	At native joint surface which directly articulates with an implant	Acetabular fracture next to hip hemiarthroplasty

Note. THR, total hip replacement.

Management

Non-operative

Patients with undisplaced fractures or those unfit for surgery may be treated non-operatively. This includes protected weight-bearing or bed rest with skin or skeletal traction. However, this should be a last resort due to the risks associated with prolonged incumbency.

Type A fractures

Minimally displaced A_G fractures can be managed with protected weight-bearing for 6–12 weeks followed by a gradual return to full weight-bearing. Displacement > 2 cm is associated with pain due to nonunion, implant loosening, trochanteric bursitis and limp from weak abductor function. Fixation options include cerclage wires/cables, cable-plate devices, claw plates and trochanteric bolts. The lowest nonunion rate is seen with simple cerclage wire/cable constructs.[41] Simple fractures can easily be treated with compression wiring or cabling whereas comminuted fractures may require a claw plate but these devices are often bulky and require removal.[42] A_L fractures are less common but if displaced can result in a loss of medial stem support and therefore should be fixed using an intraosseous cerclage trochanteric wiring technique.

Type B1 fractures

The mainstay of treatment for B1 fractures has traditionally been internal plate fixation, and, more recently, the introduction of locking cable-plate and cable-grip systems has allowed more fixation options around well-fixed stems. Stem stability must be tested intraoperatively and, if loose, the fracture must be reclassified as type B2. In the presence of a loose stem, internal fixation (IF) alone has a 34% failure rate and therefore stem exchange is recommended.[43] Successful IF also relies on adequate vascularity, an intact cement mantle, sufficient medial support and appropriate fixation either side of the fracture. The fracture pattern requires detailed consideration. Long oblique or spiral fractures can be successfully treated with plate and cerclage fixation. Balanced fixation techniques with a 'near-far configuration' should be applied where possible, ensuring that at least eight cortices either side of the fracture site are engaged.[44] Some micromotion at the fracture site helps fracture healing and too rigid a construct will lead to nonunion and metalwork failure. In elderly patients at risk of further fall, the plate should be long enough to protect the entire femur. Bicortical screws have a greater pull-out strength than unicortical screws and should be used preferentially, although placing unicortical screws in the most proximal and distal holes of the plate may allow a more even stress distribution and prevent peri-implant fracture. With cemented stems, eccentrically placed screws gain purchase into cortical bone, but where this is not possible, screws into the cement mantle are acceptable as they do not lead to a loss of structural integrity.[45] Cerclage fixation is not proven to affect periosteal blood supply,[46] and although more expensive, cable fixation provides greater stability compared to stainless steel wires.[47] Unstable fracture patterns such as transverse or short oblique fractures are prone to high rates of nonunion, and although biplanar fixation with an anterior and a lateral plate may be an option, treating these as B2 fractures with stem revision offers lower complication and reoperation rates (Fig. 2).[48,49]

Outcome of type B1 fractures

In a systematic review of 1571 PFFs (70.4% B1), Stoffel et al found that closed reduction and minimally invasive plate osteosynthesis (MIPO) using locking compression plates had significantly lower rates of nonunion (0.0% vs. 4.5%) and refracture (0.6% vs. 3.8%) compared to open reduction and conventional plating.[50] Cable-plate and cable-grip systems can both be used to treat associated trochanteric fragments and are shown to yield similar union rates (76% vs. 67%, respectively), although cable-plate systems can treat a more diverse range of fractures.[51] Castelli et al published results of a non-contact bridging locking plate in 30 patients with bony consolidation achieved at a mean of four months with no cases of mechanical failure, implant breakage or reoperation.[52] Chatziagorou et al performed a Swedish registry-based

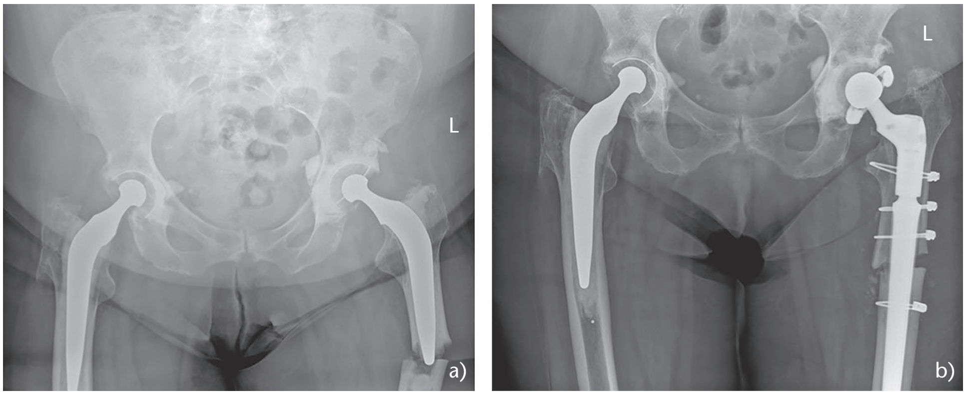

Fig. 2 (a) Unstable transverse B1 periprosthetic femoral fracture. (b) Unstable transverse B1 periprosthetic femoral fracture treated with extended trochanteric osteotomy to remove proximal cement, modular tapered cementless stem and cement-in-cement constrained acetabular component exchange.

cohort study of 1381 type B PFFs and showed that in B1 fractures (212 cases), conventional plating had a higher reoperation rate (25.8% vs. 19.3%) and femoral stem revision rate (54.5% vs. 16.7%) compared to locking plates.[53] Of all type B fractures, B1 fractures had the highest reoperation rate, possibly due to misinterpretation of stem stability, cement mantle integrity or treating unstable fracture patterns with IF.

Type B2 fractures

B2 fractures require stem exchange to achieve implant stability and fracture healing. Consideration should be given to using a large femoral head or a dual-mobility or fully constrained acetabular component to reduce the dislocation risk. A loose femoral component is relatively easy to explant but an extended trochanteric osteotomy may be useful for removing cement. Most commonly, diaphyseal fitting long cementless stems are used which need to bypass the fracture site by a minimum of 2.5 cortical diameters. These are increasingly available as tapered isthmic fitting stems with modular body, neck and head options to allow greater flexibility when balancing leg lengths and stability. These are well suited for femoral canals with divergent cortices but rely on 4–6 cm of intact isthmus for adequate press-fit.[54] The presence of fluted splines enhances rotational stability by engaging on the endosteal cortex, but if the isthmus is compromised due to fracture comminution or osteoporosis then distal fixation is required with distal locking stems.[55] Alternatively, cemented stems carry the advantages of a lower risk of iatrogenic fracture, local antibiotic delivery and immediate fixation in wide osteoporotic femurs. In the presence of well-fixed femoral cement, a quicker cement-in-cement stem exchange technique can be used effectively, particularly in elderly patients. Mild imperfections or cracks in cement mantle reduction can be 'healed' by the introduction of new cement, but large defects suggest either significant malreduction or bone loss and need to be addressed appropriately with revision to a long cementless stem or proximal femur replacement (PFR). Impaction bone grafting with morselized allograft can also be used in young patients in whom the reconstitution of bone stock is important for any future revision, but this usually involves the use of a long cemented stem.[56]

Type B3 fractures

B3 fractures involve varying amounts of bone loss due to osteolysis or fracture comminution and are the most challenging to reconstruct. In young patients in whom future revision surgery may be required, restoration of bone stock is advisable using impaction bone grafting for contained defects, cortical strut allograft for larger structural defects or resection of the proximal femur and insertion of an allograft-prosthetic composite (APC) in the form of a revision stem cemented into a proximal femoral allograft. Elderly patients may benefit from a PFR, albeit with fewer future reconstructive options and historically high complication rates such as infection, dislocation and early loosening. Technological developments including improved material, newer designs, porous or hydroxyapatite coatings and silver coating have led to increase PFR usage. Due to poor postoperative abductor function following PFR, a dual-mobility or fully constrained acetabular component should be used to reduce dislocation risk.

Outcome of type B2 and B3 fractures

Rayan et al reported on 26 patients managed with uncemented stems and a combination of allograft, cortical strut grafts, cable plating systems and demineralized bone matrix. All fractures united with a satisfactory outcome.[57] Neumann et al published the results of a distally fixed uncemented modular stem in 53 patients and found that

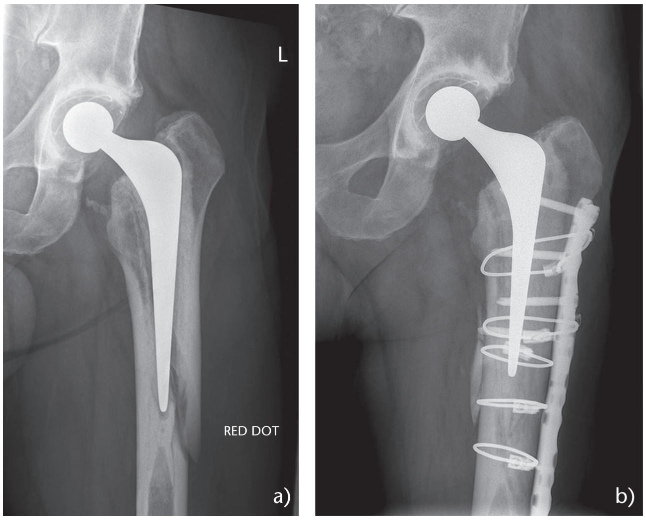

Fig. 3 (a) Type B2 periprosthetic femoral fracture around cemented polished taper-slip stem. (b) Type B2 periprosthetic femoral fracture around cemented polished taper-slip stem treated with cement-in-cement stem exchange and internal fixation with non-contact bridging locking plate.

all fractures united but 4% of stems subsided by six months.[58] Corten et al reported on 28 elderly patients (mean age 82 years) treated with open cerclage fixation, long cemented stem revision and additional cortical strut allograft in case of severe comminution.[59] Patients were permitted to weight-bear as tolerated. Although 43% died within the first year, the remainder all achieved union and no re-revisions were required. Khan et al performed a systematic review of 22 studies including 510 B2 and B3 fractures and found that 12.6% of B2 and 4.8% of B3 fractures were treated with IF alone.[60] These were associated with a higher reoperation rate compared to revision arthroplasty. This highlights the importance of stem stability assessment during preoperative work-up, intraoperative stem testing and ensuring that revision implants are available during surgery. In their registry-based cohort study, Chatziagorou et al reported an overall 18.6% reoperation rate in 1381 surgically treated type B fractures (all sub-types). In 1064 B2 and B3 fractures, there was an increased rate of reoperation with IF compared to revision surgery (18.4% vs. 13.4%) but no difference in reoperation rate between different types of revision stem (cemented, monoblock or modular cementless).[53]

Gitajn et al retrospectively reviewed 203 type B fractures and quantified one-year and five-year patient survival rates as 87% and 54%, respectively, confirming the poor long-term outcomes associated with PFFs.[7] In patients with loose stems, there was no significant difference in mortality rates between IF alone or revision arthroplasty. APC reconstruction is rarely performed for PFF but may be a viable option for young patients. Maury et al reported on 25 PFFs treated with an APC and although most were successfully treated, graft resorption occurred in 24% of cases and 16% failed due to nonunion and loosening.[61] Curtin et al treated 16 PFFs with a modular PFR and found minimal change in functional outcome compared to pre-injury status, no postoperative infections but a dislocation rate of 12.5%.[62] Viste et al published the results of 44 revision THRs using a modular porous coated PFR, including 15 for PFF with severe bone loss.[63] Dual-mobility or fully constrained acetabular components were used in 55% of cases to reduce dislocation risk. No stems were revised for aseptic loosening by ten years and overall, stem survivorship was 86% at five years and 66% years at ten years. The overall complication rate was 27% including a dislocation rate of 13.6% and a deep infection rate of 4.5%. The dislocation rate was lower in patients with constrained acetabular components (4%) which emphasizes the need for constraint during PFR.

Polished taper-slip stems

PFFs around cemented PTS stems warrant special attention as they behave differently to traditional cemented CB stems. PTS stems have excellent long-term implant survivorship but have a higher incidence of PFF compared to CB stems.[14,25,27,28] PTS stems rely on controlled subsidence within an intact cement mantle which transfers radially directed hoop stresses to cortical bone, thereby preventing stress-shielding and osteolysis. Whilst PFFs around CB stems occur later and are commonly due to osteolysis, PFFs around PTS stems occur earlier and are usually due to low-energy trauma rather than loosening.[14] This may be related to their wedge shape causing the femoral component to split the bone and cement mantle upon loading.[64,65] This often results in a damaged cement mantle that can be underestimated on radiological examination.[66] Whilst the stem may appear well-fixed, the surrounding cement mantle is often compromised, and unless a perfect reduction of both fracture and cement mantle is achieved during IF, there is potential for subsequent loosening. This can be difficult to achieve and to avoid unpredictable results, many surgeons prefer to treat all PFFs around PTS stems with stem revision. This can be achieved either by removing all the femoral cement and using a modular tapered-fluted stem or via a cement-in-cement stem exchange technique (Fig. 3). An alternative strategy in frail and elderly patients is to perform IF alone to encourage femoral union whilst accepting that subsidence and thigh pain may occur in future. There is a paucity of literature on the outcomes of PFFs around PTS stems. Goudie et al reported a union rate of 91% in a series of 79 patients treated with IF over a five-year period and found that non-anatomic reduction and infection were associated with nonunion.[67] Maggs et al reported a series of cement-in-cement revision in 48 patients with

Table 2. Pires classification of interprosthetic fractures.

Type	Subtype	Treatment
1 Interprosthetic fracture surrounding hip replacement	**A** Stable implants **B** Unstable hip implant; stable knee implant **C** Stable hip implant; unstable knee implant **D** Both hip and knee implants unstable	Spanning locking plate +/- cerclage fixation Hip stem revision +/- locking plate +/- cerclage fixation Stemmed knee revision + spanning locking plate +/- cerclage fixation Total femur replacement
2 Interprosthetic fracture surrounding knee replacement without stem	**A** Stable implants **B** Unstable hip implant; stable knee implant **C** Stable hip implant; unstable knee implant **D** Both hip and knee implants unstable	Spanning locking plate +/- cerclage fixation Hip stem revision + locking plate +/- cerclage fixation Stemmed knee revision + locking plate +/- cerclage fixation Total femur replacement
3 Interprosthetic fracture surrounding stemmed knee replacement	**A** Stable implants with good interprosthetic bone stock **B** Stable implants with poor interprosthetic bone stock **C** Unstable implants (hip, knee, or both) with good interprosthetic bone stock **D** Unstable implants (hip, knee, or both) with poor interprosthetic bone stock	Spanning locking plate +/- cerclage fixation +/- bone graft Total femur replacement OR locking plate +/- bone graft Total femur replacement OR both implant revision + locking plate + bone graft Total femur replacement OR both implant revision + locking plate + bone graft

supplementary fixation with cables, wires or plates.[68] They stated a 95% union rate and a 4.1% reoperation rate for nonunion.

Type C fractures

Type C fractures are effectively distal femur fractures and can be managed independently of the stem. IF is recommended for medically fit patients to promote early mobilization and avoid the risks of prolonged cast treatment. Options include plating through open or MIPO techniques or retrograde intramedullary nailing. Modern periarticular plates are precontoured and have locking polyaxial screw and cerclage options available for improved purchase in osteoporotic bone. Plates should be long enough to overlap the stem in order to avoid a stress riser and should include fixation up to the greater trochanter in patients at risk of further falls. Concerns that modern locking plates are too rigid and may lead to nonunion have been raised, but recent clinical evidence does not support this.[69,70] This inconsistency is more likely related to surgical technique rather than plate material and therefore, a large working length or bridging gap should be maintained to promote relative stability and fracture healing.[71] Retrograde intramedullary nailing is less invasive than open reduction techniques but is often limited by the stem, poor bone quality for distal locking screws and the potential for a stress riser. Innovative solutions include nailed cementoplasty, where the nail is augmented with bone cement, combined nail-plate constructs and docking nails which engage with the stem tip, although evidence supporting these techniques is scarce.[72-74] High-quality prospective data comparing plating to nailing for PFFs is lacking, but a recent retrospective cohort study into 639 type C fractures found a significantly lower reoperation rate with locking plates (11.8%) compared to conventional plates (26.1%) and intramedullary nailing (24.2%).[70]

Type D fractures

Type D fractures are interprosthetic femoral fractures (IFF) occurring between THR and total knee replacement (TKR). Their incidence is rising and is now estimated at 5–7% of all PFFs.[75,76] Risk factors include elderly females over 75 years, cementless stems, reduced femoral cortex width and a distance of less than 110 mm between femoral implants.[77,78] Pires et al describe a validated classification system which subclassifies fractures into three main types (Table 2).[79,80] Considerations include fracture location, implant stability, bone loss and the presence of a stemmed TKR femoral implant. Type A fractures around stable implants can be managed with spanning locking plates and cerclage fixation. Locking plates should span the entire femur to provide adequate stability. Other options include combined retrograde intramedullary nailing and either a lateral locking plate or an interposition sleeve to engage stemmed implants where fracture fixation cannot be achieved.[81-83] Fractures around either loose THR (type B) or loose TKR (type C) implants require IF and stemmed revision. Type D fractures where both THR and TKR implants are loose or where there is severely compromised interprosthetic bone stock require revision surgery and femoral reconstruction with cortical strut allografts, interposition sleeves or total femur replacement (TFR).

Outcome of type D fractures

Hoffmann et al reported an 89% union rate in a series of 32 IFFs treated with a Non-Contact Bridging (NCB) polyaxial locking plate with a two-year follow up period.[84] All cases of nonunion were in Arbeitsgemeinschaft Fur Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) type B ‘wedge’ femoral fractures and were successfully treated with longer plates. Abdelaziz et al report a 20-year experience of using custom-made interposition sleeves in 26 patients with minimum one-year follow-up.[85] Mean sleeve survivorship was 4.6 years but the overall rate of complication was high at 47.8% including mechanical failure (21.7%) and infection (13%). Jennison and Yarlagadda published on 24 IFFs over a seven-year period treated with IF (19 cases), revision TKR (two cases) or revision THR (three cases).[86] Fracture union was achieved in 82.6%, reoperation was required in 12.5% and two-year mortality was 20.8%. IF was associated with a lower rate of complication and is recommended over revision surgery where possible. Bonevialle et al have reported the largest contemporary series of IFFs in 51 patients treated with IF (47 cases), revision THR (two cases), external fixator (one case) or non-operatively (one case).[76] Mean time to union was 19.25 weeks, surgical site infection rate was 24%, major revision rate was 24% and mortality rate was 31% with a median survival of 3.45 years. These studies reflect the complicated nature of IFFs and the need for experienced and specialized surgeons managing this most complex form of PFF.

Type E and F fractures

Type E and F fractures surrounding acetabular implants are outside the scope of this article, but the reader is encouraged to study the principles of acetabular fracture fixation and implant revision in the presence of unstable implants and bone loss.

Financial implications

The financial burden of treating PFFs has been examined across several different healthcare systems and is expected to rise. The mean cost of treating 146 PFFs from a UK trauma centre was £23,469 (range, £615–223,000) with inpatient ward costs responsible for 80.3% of expenditure.[87] At a UK specialist tertiary referral centre, the median cost of treating 75 PFFs was £13,381 (range, £1,006–53,763) with an overall loss of £373,737 over a two-year period.[88] US data also support these high treatment costs, with readmission costs for PFF calculated at $17,206 for IF and $16,504 for revision surgery.[89] Furthermore, local hospitalization costs have been shown to be significantly higher for PFF revision surgery ($25,672) compared to revision surgery for aseptic loosening ($20,228) or dislocation ($17,911).[90] Comparison of costs between different healthcare providers must be undertaken cautiously due to inherent differences in service provision, financial infrastructure and lack of transparency regarding patient-related costs. Nevertheless, the cost of treating PFFs is high, and there is a growing need for centralizing these complex cases in order to lower treatment costs.[91]

Conclusion

Current data confirm the increasing burden of PFF from both clinical and financial perspectives. Whilst there has been considerable focus on the management of these complex fractures, further research is required into preventative strategies that can be employed at the time of primary THR. Further epidemiological data through interrogation of healthcare databases can help identify modifiable risk factors related to surgical technique and implant design. The introduction of national PFF-specific databases would be invaluable in the collection of high-quality prospective data. A greater focus on identifying and treating at-risk patients with metabolic bone disease prior to THR through an effective screening programme may also offer a preventive strategy. Finally, as large endoprostheses such as PFR and TFR are likely to be used more frequently, robust long-term clinical data are required in order to identify areas for technological improvement, particularly with regard to loosening, instability and infection.

AUTHOR INFORMATION

[1]Department of Orthopaedic Surgery, Chapel Allerton Hospital, Leeds, UK.
[2]University of Leeds, Leeds, UK.

Correspondence should be sent to: Ashoklal Ramavath, Leeds Teaching Hospitals NHS Trust, Chapel Allerton Hospital, Leeds, LS7 4SA, UK.
Email: ashoklal.ramavath@nhs.net

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

ICMJE CONFLICT OF INTEREST STATEMENT

JNL reports consultancy for Zimmer Biomet, grants/grants pending from DePuy Synthese and AO UK, and a Charnley Charitable Trust travelling grant for travel to an international presentation at AAOS 2019, all outside the submitted work.
HGP reports consultancy for Zimmer Biomet, Depuy Synthes, Meril Life, JRI, GSK and Medacta Int., expert testimony for Kennedy's Law, grants/grants pending from Zimmer Biomet, Depuy Synthes, GSK, Invibio and NIHR, and payment for manuscript preparation from Smith & Nephew, all outside the submitted work.
The other authors declare no conflict of interest relevant to this work.

REFERENCES

1. **Learmonth ID, Young C, Rorabeck C.** The operation of the century: total hip replacement. *Lancet* 2007;370:1508–1519.

2. **OECD.** Hip and knee replacement. In *Health at a glance* 2017: OECD indicators. Paris: OECD Publishing.

3. **Abdel MP, Watts CD, Houdek MT, Lewallen DG, Berry DJ.** Epidemiology of periprosthetic fracture of the femur in 32 644 primary total hip arthroplasties: a 40-year experience. *Bone Joint J* 2016;98-B:461–467.

4. **Pivec R, Issa K, Kapadia BH, et al.** Incidence and future projections of periprosthetic femoral fracture following primary total hip arthroplasty: an analysis of international registry data. *J Long Term Eff Med Implants* 2015;25:269–275.

5. **National Joint Registry 16th Annual Report 2019: https://reports.** njrcentre.org.uk/Portals/0/PDFdownloads/NJR%2016th%20Annual%20Report%202019.pdf (date last accessed 8th January 2020).

6. **Shields E, Behrend C, Bair J, Cram P, Kates S.** Mortality and financial burden of periprosthetic fractures of the femur. *Geriatr Orthop Surg Rehabil* 2014;5:147–153.

7. **Gitajn IL, Heng M, Weaver MJ, et al.** Mortality following surgical management of Vancouver B periprosthetic fractures. *J Orthop Trauma* 2017;31:9–14.

8. **Thien TM, Chatziagorou G, Garellick G, et al.** Periprosthetic femoral fracture within two years after total hip replacement: analysis of 437,629 operations in the Nordic Arthroplasty Register Association database. *J Bone Joint Surg Am* 2014;96:e167.

9. **Brodén C, Mukka S, Muren O, et al.** High risk of early periprosthetic fractures after primary hip arthroplasty in elderly patients using a cemented, tapered, polished stem. *Acta Orthop* 2015;86:169–174.

10. **Katz JN, Wright EA, Polaris JJ, Harris MB, Losina E.** Prevalence and risk factors for periprosthetic fracture in older recipients of total hip replacement: a cohort study. *BMC Musculoskelet Disord* 2014;15:168.

11. **Gromov K, Bersang A, Nielsen CS, Kallemose T, Husted H, Troelsen A.** Risk factors for post-operative periprosthetic fractures following primary total hip arthroplasty with a proximally coated double-tapered cementless femoral component. *Bone Joint J* 2017;99-B:451–457.

12. **Singh JA, Jensen M, Harmsen S, Lewallen D.** Are gender, comorbidity and obesity risk factors for postoperative periprosthetic fractures following primary total hip replacement? *J Arthroplasty* 2013;28:126–131.

13. **Lindberg-Larsen M, Jørgensen CC, Solgaard S, Kjersgaard AG, Kehlet H, Lunbeck Foundation Centre for Fast-track Hip and Knee Replacement.** Increased risk of intraoperative and early postoperative periprosthetic femoral fracture with uncemented stems. *Acta Orthop* 2017;88:390–394.

14. **Palan J, Smith MC, Gregg P, et al.** The influence of cemented femoral stem choice on the incidence of revision for periprosthetic fracture after primary total hip arthroplasty: an analysis of national joint registry data. *Bone Joint J* 2016;98-B:1347–1354.

15. **Chatziagorou G, Lindahl H, Kärrholm J.** The design of the cemented stem influences the risk of Vancouver type B fractures, but not of type C: an analysis of 82,837 Lubinus SPII and Exeter polished stems. *Acta Orthop* 2019;90:135–142.

16. **Watts CD, Abdel MP, Lewallen DG, Berry DJ, Hanssen AD.** Increased risk of periprosthetic femur fractures associated with a unique cementless stem design. *Clin Orthop Relat Res* 2015;473:2045–2053.

17. **Singh JA, Lewallen DG.** Peptic ulcer disease and heart disease are associated with periprosthetic fractures after total hip replacement. *Acta Orthop* 2012;83:353–359.

18. **Dorr LD, Faugere MC, Mackel AM, Gruen TA, Bognar B, Malluche HH.** Structural and cellular assessment of bone quality of proximal femur. *Bone* 1993;14:231–242.

19. **Berend KR, Mirza AJ, Morris MJ, Lombardi AV Jr.** Risk of periprosthetic fractures with direct anterior primary total hip arthroplasty. *J Arthroplasty* 2016;31:2295–2298.

20. **Siljander MP, Whaley JD, Koueiter DM, Alsaleh M, Karadsheh MS.** Length of stay, discharge disposition, and 90-day complications and revisions following primary total hip arthroplasty: a comparison of the direct anterior, posterolateral, and direct superior approaches. *J Arthroplasty* 2020;35:1658–1661.

21. **Aggarwal VK, Elbuluk A, Dundon J, et al.** Surgical approach significantly affects the complication rates associated with total hip arthroplasty. *Bone Joint J* 2019;101-B:646–651.

22. **Jando V, Duffy P, Masri B, Duncan C, et al.** Management of periprosthetic fractures. In: Callaghan JJ, Rosenberg AG, Rubash HE, eds. *The adult hip*. Vol. 2 ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2007:1211

23. **Berend ME, Smith A, Meding JB, Ritter MA, Lynch T, Davis K.** Long-term outcome and risk factors of proximal femoral fracture in uncemented and cemented total hip arthroplasty in 2551 hips. *J Arthroplasty* 2006;21:53–59.

24. **Carli AV, Negus JJ, Haddad FS.** Periprosthetic femoral fractures and trying to avoid them: what is the contribution of femoral component design to the increased risk of periprosthetic femoral fracture? *Bone Joint J* 2017;99-B:50–59.

25. **Kristensen TB, Dybvik E, Furnes O, Engesæter LB, Gjertsen JE.** More reoperations for periprosthetic fracture after cemented hemiarthroplasty with polished taper-slip stems than after anatomical and straight stems in the treatment of hip fractures. *Bone Joint J* 2018 Dec;100-B:1565–1571.

26. **Mukka S, Mellner C, Knutsson B, Sayed-Noor A, Sköldenberg O.** Substantially higher prevalence of postoperative peri-prosthetic fractures in octogenarians with hip fractures operated with a cemented, polished tapered stem rather than an anatomic stem. *Acta Orthop* 2016;87:257–261.

27. **Lamb JN, Baetz J, Messer-Hannemann P, Adekanmbi I, Duren BHv, Redmond A, et al.** A calcar collar is protective against early periprosthetic femoral fracture around cementless femoral components in primary total hip arthroplasty. *Bone Joint J* 2019;101-B:779–786.

28. **Reid IR, Bolland MJ, Grey A.** Effects of vitamin D supplements on bone mineral density: a systematic review and meta-analysis. *Lancet* 2014;383:146–155.

29. **Lin T, Yan SG, Cai XZ, Ying ZM.** Bisphosphonates for periprosthetic bone loss after joint arthroplasty: a meta-analysis of 14 randomized controlled trials. *Osteoporos Int* 2012;23:1823–1834.

30. **MacKenzie SA, Ng RT, Snowden G, Powell-Bowns MFR, Duckworth AD, Scott CEH.** Periprosthetic atypical femoral fractures exist and are associated with duration of bisphosphonate therapy. *Bone Joint J* 2019;101-B:1285–1291.

31. **Grosso MJ, Courtland HW, Yang X, et al.** Intermittent PTH administration and mechanical loading are anabolic for periprosthetic cancellous bone. *J Orthop Res* 2015;33:163–173.

32. **Lee YK, Kim JT, Kim KC, Ha YC, Koo KH.** Conservative treatment for minimally displaced type B periprosthetic femoral fractures. *J Arthroplasty* 2017;32:3529–3532.

33. **Ochi K, Ikari K, Naomi A, Momohara S.** Administration of teriparatide treatment for a challenging case of nonunion of periprosthetic fracture after total knee arthroplasty. *Arch Osteoporos* 2013;8:159.

34. **Chevillotte CJ, Ali MH, Trousdale RT, Larson DR, Gullerud RE, Berry DJ.** Inflammatory laboratory markers in periprosthetic hip fractures. *J Arthroplasty* 2009;24:722–727.

35. **Marsland D, Mears SC.** A review of periprosthetic femoral fractures associated with total hip arthroplasty. *Geriatr Orthop Surg Rehabil* 2012;3:107–120.

36. **Katzer A, Ince A, Wodtke J, Loehr JF.** Component exchange in treatment of periprosthetic femoral fractures. *J Arthroplasty* 2006;21:572–579.

37. **Naqvi GA, Baig SA, Awan N.** Interobserver and intraobserver reliability and validity of the Vancouver classification system of periprosthetic femoral fractures after hip arthroplasty. *J Arthroplasty* 2012;27:1047–1050.

38. **Duncan CP, Haddad FS.** The Unified Classification System (UCS): improving our understanding of periprosthetic fractures. *Bone Joint J* 2014;96-B:713–716.

39. **Huang JF, Chen JJ, Shen JJ, Du WX, Liu FC, Tong PJ.** The reliability and validity of the Unified Classification System of periprosthetic femoral fractures after hip arthroplasty. *Acta Orthop Belg* 2016;82:233–239.

40. **Lee S, Kagan R, Wang L, Doung YC.** Reliability and validity of the Vancouver classification in periprosthetic fractures around cementless femoral stems. *J Arthroplasty* 2019;34:S277–S281.

41. **Mei XY, Gong YJ, Safir OA, Gross AE, Kuzyk PR.** Fixation options following greater trochanteric osteotomies and fractures in total hip arthroplasty: a systematic review. *JBJS Rev* 2018;6:e4.

42. **Hamadouche M, Zniber B, Dumaine V, Kerboull M, Courpied JP.** Reattachment of the ununited greater trochanter following total hip arthroplasty: the use of a trochanteric claw plate. *J Bone Joint Surg Am* 2003;85:1330–1337.

43. **Lindahl H, Malchau H, Herberts P, Garellick G.** Periprosthetic femoral fractures classification and demographics of 1049 periprosthetic femoral fractures from the Swedish National Hip Arthroplasty Register. *J Arthroplasty* 2005;20:857–865.

44. **Pike J, Davidson D, Garbuz D, Duncan CP, O'Brien PJ, Masri BA.** Principles of treatment for periprosthetic femoral shaft fractures around well-fixed total hip arthroplasty. *J Am Acad Orthop Surg* 2009;17:677–688.

45. **Bibiano L, Stamboltsyan G, Touloupakis G, et al.** Plate fixation in periprosthetic femur fractures Vancouver type B1: preliminary report of macroscopic evaluation of the cement mantle and short literature review. *Acta Biomed* 2019;90:31–36.

46. **Lenz M, Perren SM, Gueorguiev B, et al.** Underneath the cerclage: an ex vivo study on the cerclage-bone interface mechanics. *Arch Orthop Trauma Surg* 2012;132:1467–1472.

47. **Carls J, Kohn D, Rössig S.** A comparative study of two cerclage systems. *Arch Orthop Trauma Surg* 1999;119:67–72.

48. **Pavlou G, Panteliadis P, Macdonald D, et al.** A review of 202 periprosthetic fractures: stem revision and allograft improves outcome for type B fractures. *Hip Int* 2011;21:21–29.

49. **Chakrabarti D, Thokur N, Ajnin S.** Cable plate fixation for Vancouver Type-B1 periprosthetic femoral fractures: our experience and identification of a subset at risk of non-union. *Injury* 2019;50:2301–2305.

50. **Stoffel K, Sommer C, Kalampoki V, Blumenthal A, Joeris A.** The influence of the operation technique and implant used in the treatment of periprosthetic hip and interprosthetic femur fractures: a systematic literature review of 1571 cases. *Arch Orthop Trauma Surg* 2016;136:553–561.

51. **Ricciardi BF, Nodzo SR, Oi K, Lee YY, Westrich GH.** Radiographic outcomes of cable-plate versus cable-grip fixation in periprosthetic fractures of the proximal femur. *Hip Int* 2017;27:584–588.

52. **Castelli A, Rossi SMP, Rocca L, Jannelli E, Benazzo F.** Treatment of Vancouver B1, C periprosthetic hip fractures with periprosthetic polyaxial locking plate system: a 3-year follow-up. *J Biol Regul Homeost Agents* 2018;32:209–216.

53. **Chatziagorou G, Lindahl H, Kärrholm J.** Surgical treatment of Vancouver type B periprosthetic femoral fractures: patient characteristics and outcomes of 1381 fractures treated in Sweden between 2001 and 2011. *Bone Joint J* 2019;101-B:1447–1458.

54. **Paprosky W.** Fluted tapered modular stems: accommodating bone loss deficiency. *Bone Joint J* 2013;95-B(11 Suppl A):95-97.

55. **Haidukewych GJ, Langford J, Liporace FA.** Revision for periprosthetic fractures of the hip and knee. *J Bone Joint Surg Am* 2013;95:368–376.

56. **Youssef B, Pavlou G, Shah N, Macheras G, Tsiridis E.** Impaction bone grafting for periprosthetic fractures around a total hip arthroplasty. *Injury* 2014;45:1674–1680.

57. **Rayan F, Konan S, Haddad FS.** Uncemented revision hip arthroplasty in B2 and B3 periprosthetic femoral fractures: a prospective analysis. *Hip Int* 2010;20:38–42.

58. **Neumann D, Thaler C, Dorn U.** Management of Vancouver B2 and B3 femoral periprosthetic fractures using a modular cementless stem without allografting. *Int Orthop* 2012;36:1045–1050.

59. **Corten K, Macdonald SJ, McCalden RW, Bourne RB, Naudie DD.** Results of cemented femoral revisions for periprosthetic femoral fractures in the elderly. *J Arthroplasty* 2012;27:220–225.

60. **Khan T, Grindlay D, Ollivere BJ, Scammell BE, Manktelow AR, Pearson RG.** A systematic review of Vancouver B2 and B3 periprosthetic femoral fractures. *Bone Joint J* 2017;99-B:17–25.

61. **Maury AC, Pressman A, Cayen B, Zalzal P, Backstein D, Gross A.** Proximal femoral allograft treatment of Vancouver type-B3 periprosthetic femoral fractures after total hip arthroplasty. *J Bone Joint Surg Am* 2006;88:953–958.

62. **Curtin M, Bryan C, Murphy E, Murphy CG, Curtin W.** Early results of the LPS™ limb preservation system in the management of periprosthetic femoral fractures. *J Orthop* 2016;14:34–37.

63. **Viste A, Perry KI, Taunton MJ, Hanssen AD, Abdel MP.** Proximal femoral replacement in contemporary revision total hip arthroplasty for severe femoral bone loss: a review of outcomes. *Bone Joint J* 2017;99-B:325–329.

64. **Sarvilinna R, Huhtala H, Pajamäki J.** Young age and wedge stem design are risk factors for periprosthetic fracture after arthroplasty due to hip fracture: a case-control study. *Acta Orthop* 2005;76:56–60.

65. **Phillips JR, Moran CG, Manktelow AR.** Periprosthetic fractures around hip hemiarthroplasty performed for hip fracture. *Injury* 2013;44:757–762.

66. **Quah C, Porteous M, Stephen A.** Principles of managing Vancouver type B periprosthetic fractures around cemented polished tapered femoral stems. *Eur J Orthop Surg Traumatol* 2017;27:477–482.

67. **Goudie ST, Patil S, Patton JT, Keating JF.** Outcomes following osteosynthesis of periprosthetic hip fractures around cemented tapered polished stems. *Injury* 2017;48:2194–2200.

68. **Maggs J, Swanton E, Wilson M, Gie G.** Cement in cement revision for periprosthetic fractures around cemented taper-slip stems. *Orthopaedic Proceedings* 2018;100-B:13.

69. **Karam J, Campbell P, David M, Hunter M.** Comparison of outcomes and analysis of risk factors for non-union in locked plating of closed periprosthetic and non-periprosthetic distal femoral fractures in a retrospective cohort study. *J Orthop Surg Res* 2019;14:150.

70. **Chatziagorou G, Lindahl H, Kärrholm J.** Lower reoperation rate with locking plates compared with conventional plates in Vancouver type C periprosthetic femoral fractures: a register study of 639 cases in Sweden. *Injury* 2019;50:2292–2300.

71. **Moazen M, Jones AC, Leonidou A, Jin Z, Wilcox RK, Tsiridis E.** Rigid versus flexible plate fixation for periprosthetic femoral fracture: computer modelling of a clinical case. *Med Eng Phys* 2012;34:1041–1048.

72. **Kyriakidis T, Kenanidis E, Akula MR, Zorman D, Tsiridis E.** Locking plates versus retrograde intramedullary nails in the treatment of periprosthetic supracondylar knee fractures: a retrospective multicenter comparative study. *Injury* 2019;50:1745–1749.

73. **Mirick Mueller GE.** Nail-plate constructs for periprosthetic distal femur fractures. *J Knee Surg* 2019;32:403–406.

74. **Butler BA, Harold RE, Williams J.** Prosthesis-engaging retrograde femoral nail with locking plate for the treatment of a Vancouver B1 periprosthetic femur fracture nonunion: a case report. *JBJS Case Connect* 2019;9:e0108.

75. **Kenny P, Rice J, Quinlan W.** Interprosthetic fracture of the femoral shaft. *J Arthroplasty* 1998;13:361–364.

76. **Bonnevialle P, Marcheix PS, Nicolau X, et al; members of the Getraum.** Interprosthetic femoral fractures: morbidity and mortality in a retrospective, multicenter study. *Orthop Traumatol Surg Res* 2019;105:579–585.

77. **Valle Cruz JA, Urda AL, Serrano L, et al.** Incidence of and risk factors for femoral fractures in the gap between hip and knee implants. *Int Orthop* 2016;40:1697–1702.

78. **Lipof JS, Amitai AD, Judd KT, Gorczyca JT.** Radiographic risk factors for interprosthetic femur fractures. *Iowa Orthop J* 2017;37:35–39.

79. **Soenen M, Baracchi M, De Corte R, Labey L, Innocenti B.** Stemmed TKA in a femur with a total hip arthroplasty: is there a safe distance between the stem tips? *J Arthroplasty* 2013;28:1437–1445.

80. **Pires RE, de Toledo Lourenço PR, Labronici PJ, et al.** Interprosthetic femoral fractures: proposed new classification system and treatment algorithm. *Injury* 2014;45:S2–S6.

81. **Jennison T, Jawed A, ElBakoury A, Hosny H, Yarlagadda R.** Reliability of the commonly used classification systems for interprosthetic fractures. *Eur J Orthop Surg Traumatol* 2019;29:1069–1072.

82. **Weiser L, Korecki MA, Sellenschloh K, et al.** Interposition sleeve as treatment option for interprosthetic fractures of the femur: a biomechanical in vitro assessment. *Int Orthop* 2015;39:1743–1747.

83. **Hussain MS, Dailey SK, Avilucea FR.** Stable fixation and immediate weight-bearing after combined retrograde intramedullary nailing and open reduction internal fixation of noncomminuted distal interprosthetic femur fractures. *J Orthop Trauma* 2018;32:e237–e240.

84. **Hoffmann MF, Lotzien S, Schildhauer TA.** Clinical outcome of interprosthetic femoral fractures treated with polyaxial locking plates. *Injury* 2016;47:934–938.

85. **Abdelaziz H, Saleri S, Mau H, et al.** Interprosthetic femoral sleeves in revision arthroplasty: a 20-year experience. *J Arthroplasty* 2019;34:1423–1429.

86. **Jennison T, Yarlagadda R.** Outcome of surgical treatment of inter prosthetic fractures: a case series. *Orthop Traumatol Surg Res* 2019;105:587–589.

87. **Phillips JR, Boulton C, Morac CG, Manktelov AR.** What is the financial cost of treating periprosthetic hip fractures? *Injury* 2011;42:146–149.

88. **Jain S, Divecha H, Rajpura A, Shah N, Board T, Wynn Jones H.** The financial impact of treating periprosthetic fractures at a specialist tertiary referral centre [abstract]. *British Hip Society Meeting*, 2018.

89. **Reeves RA, Schairer WW, Jevsevar DS.** The national burden of periprosthetic hip fractures in the US: costs and risk factors for hospital readmission. *Hip Int* 2019;29:550–557.

90. **Hevesi M, Wyles CC, Yao JJ, et al.** Revision total hip arthroplasty for the treatment of fracture: more expensive, more complications, same diagnosis-related groups: a local and national cohort study. *J Bone Joint Surg Am* 2019;101:912–919.

91. **Barratt H, Turner S, Hutchings A, et al.** Mixed methods evaluation of the Getting it Right First Time programme: improvements to NHS orthopaedic care in England: study protocol. *BMC Health Serv Res* 2017;17:71.