Chapter 7
Periprosthetic Femur Fractures After Total Hip Arthroplasty

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Introduction

Total hip arthroplasty (THA) is often regarded as the most effective treatment of painful hip arthritis. In 2007, Learmonth and colleagues recognized THA as the "operation of the century" [1]. One potentially devastating complication of an otherwise extremely successful surgery is a periprosthetic fracture. The rate of fracture after total hip arthroplasty ranges from 0.1% to 18% [2]. In a landmark study using data from the Swedish Hip Arthroplasty Register, Lindahl and colleagues found the annual incidence of periprosthetic fractures to be 0.4% after primary THA and 2.1% after revision THA [3]. Using the Mayo Clinic Joint Replacement Database, Berry and colleagues analyzed 23,980 primary THAs and 6349 revision THAs and found an incidence of 1% in primary THA and 4% in revision THA [4].

The prevalence of periprosthetic fractures after THA is increasing [4–8]. There are multiple proposed reasons for the observed increase in complication rate. First, the annual number of THAs performed worldwide is increasing – this is accompanied by a concomitant rise in the absolute volume of known surgical complications, including periprosthetic fracture [9]. Second, the increase in volume of primary procedures inevitably leads to an increase in revision THAs, which have been shown to have higher rate of periprosthetic fracture [8]. Third, as medical therapies advance and patients live longer, they are at higher risk of developing osteoporosis and subsequently a low-energy periprosthetic fracture.

Treatment of periprosthetic fractures can be complex, as it often requires the surgeon to concurrently address multiple problems, including osteolysis, fracture reduction, and implant stability. Accordingly, periprosthetic fractures are generally managed

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by surgeons with specialized training in revision arthroplasty. However, given the popularity of THA, all orthopaedic surgeons should be aware of the initial workup, management principles, and indications for referral to a specialized center. Thus, the purpose of this chapter is to provide a comprehensive overview of periprosthetic hip fractures, including initial presentation, clinical evaluation, treatment modalities, and expected outcomes. Though periprosthetic hip fractures may involve the acetabulum, the femur is most commonly affected and will therefore be the focus of this review [10].

Risk Factors

Risk factors for periprosthetic fracture can be grouped into patient factors, surgical factors, and anatomical factors. Patient-specific factors associated with increased rate of periprosthetic fracture include older age, female gender, and higher body mass index (BMI) [11–13]. Notably, however, while older age and female gender are commonly listed as independent risk factors of periprosthetic fracture, the data supporting these conclusions are often confounded by the presence of osteoporosis [13]. Other patient-specific factors to consider include initial indication for THA, as patients undergoing THA for hip fracture have been shown to be at higher risk of subsequent periprosthetic fracture than patients who undergo a THA for osteoarthritis (OA) [14, 15]. This difference is likely secondary to the higher rate of osteoporosis seen in the hip fracture patient population versus the OA patient population. Any systemic illness known to be associated with reduced bone mineral density, such as chronic corticosteroid use, alcoholism, substance abuse, or rheumatoid arthritis, increases patients' risk of periprosthetic fracture [16]. Similarly, neuromuscular disorders which predispose patients to falls, such as dementia or Parkinson's disease, increase risk of periprosthetic fracture [17, 18].

Surgical factors associated with higher risk of periprosthetic fracture are largely related to implant type and method of fixation. For both primary and revision surgery, risk of periprosthetic fracture is significantly increased with the use of uncemented femoral components [4, 12, 19–21]. Abdel et al. found a 14-fold increased risk of intraoperative periprosthetic fracture when a cementless femoral component was used in primary THA [8]. Herndon et al. found that increasing Dorr ratio, defined as inner canal diameter 10 cm distal to the midportion of the lesser trochanter divided by inner canal diameter at the midportion of the lesser trochanter, was associated with a higher rate of periprosthetic fracture [22]. In a recent systematic review and meta-analysis, Carli et al. found single-wedge and double-wedge femoral implants to be associated with a threefold increase in periprosthetic fracture rate as compared with anatomical, fully coated and tapered stems [21]. Additionally, the authors noted that among cemented stems, Exeter stems (loaded-taper) were associated with higher rate of periprosthetic fracture than Charnley stems (composite-beam) [21].

Anatomical factors associated with higher risk of periprosthetic fracture include anatomic abnormalities of the proximal femur, tumor, and prior surgery involving the ipsilateral proximal femur [18]. Additionally, osteolysis of the greater trochanter has been shown to be associated with an increased rate of periprosthetic fracture [11, 23].

Clinical Evaluation

History and Physical Examination

A thorough history and physical exam is a mandatory aspect of the workup in a patient with a suspected periprosthetic fracture. Low-energy falls from a sitting or standing position have been shown to cause 75% of periprosthetic femur fractures after primary THA and 56% of fracture after revision THA [11, 24, 25]. Patients with low-energy injury mechanisms should be evaluated for possible medical causes of their fall, such as syncope, acute coronary syndrome, arrhythmia, head injury, or cerebrovascular accident. As such, “mechanical fall” should be a diagnosis of exclusion, particularly in the geriatric patient population with multiple medical comorbidities. Contributing medical conditions, when identified, should be co-managed with the appropriate medical specialty. Less commonly, younger patients with higher levels of activity may experience fracture secondary to high-energy trauma, but this comprises <10% of reported cases [26].

It is important to determine pre-injury functional status, including the presence or absence of thigh pain, or pain with initiation of motion after sitting (“start-up” pain) as these symptoms can indicate a loose femoral component. If possible, the surgeon should obtain the patient’s medical record, including prior operative reports and radiographs, as they are helpful to properly identify the devices currently implanted as well as pertinent prior surgical details such as abnormal anatomy or intraoperative complications. If outside records are not available, consultation with senior surgeons or experienced industry representatives is often successful in identifying the patient’s implants. Recently, Karnuta et al. have shown that artificial intelligence can be used to identify arthroplasty implants using hip radiographs with 99% accuracy [27].

After a general assessment, a secondary survey, and, if appropriate, completion of Advanced Trauma Life Support (ATLS) protocols, attention should be turned to the exam of the affected extremity. Given the robust soft tissue sleeve of the surrounding area, gross deformity is not often seen. However, as with all orthopaedic patients, exam and documentation of the skin and distal neurovascular status are mandatory.

Imaging Studies

An anteroposterior (AP) pelvis and standard AP and lateral radiographs of the affected hip should be obtained. These views allow for determination of important fracture characteristics, component positioning, degree of osteolysis, adequacy of bone stock, and implant stability. It is also important to obtain full-length femur radiographs as they better allow full assessment of fracture propagation distally, the presence of distal femur hardware, and any complicating femoral anatomy. Furthermore, these images should be compared and scrutinized against previous radiographs, whenever available, to elucidate progression in loosening or osteolysis and assess for any subtle subsidence or shift in implant position. Routinely obtaining advanced imaging such as computed tomography (CT) scans, magnetic resonance imaging (MRI), or ultrasound is not warranted, though the improved detail provided by CT scans can be helpful for surgical planning. CT can occasionally be helpful in identifying subtle nondisplaced fracture extension from the stem tip and may provide further insight into osteointegration of uncemented implants when radiographs are not definitive.

Laboratory Investigations

In the setting of a fracture, erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level are not sensitive indicators of infection, as they are increased with trauma due to the inherent inflammation [13]. In a retrospective review of 204 patients with periprosthetic hip fracture, Chevillotte et al. found a false-positive rate for infection of 43% for CRP level and 31% for ESR [28]. Therefore, Pike et al. argue that in the absence of evidence of infection on history and exam, and with radiographs that demonstrate a stable THA, surgeons may proceed with operative intervention without further infectious workup [13]. Shah and associates evaluated the efficacy of common diagnostic tests for periprosthetic joint infection and found synovial white blood cell (WBC) count with a cutoff of 2707 WBC/uL and differential cutoff of 77% polymorphonuclear cells to be the best diagnostic predictors of infection [29]. Surgeons may choose to send frozen section specimens if suspicions of infection based on patient history, physical exam, or imaging [13]. The patient may be further evaluated with image-guided hip joint aspiration with subsequent gram stain and culture, though this delays operative intervention by 5–7 days. Routine tissue cultures for permanent analysis should be sent in the setting of all revision arthroplasty procedures.

Classification

The Vancouver classification, initially proposed in 1995 by Duncan and Masri, is considered one of the most useful classification systems in orthopaedics due to its ability to direct treatment and prognosis [30, 31]. The classification system was initially designed to describe postoperative periprosthetic femur fractures but has since been modified by Masri et al. to include both intraoperative and postoperative fractures [32]. The intraoperative fracture classification focuses primarily on fracture location, pattern, and stability, while the postoperative classification emphasizes not only fracture location but also implant stability and adequacy of femoral bone stock (Tables 7.1 and 7.2). The Vancouver classification has been validated by multiple investigators [33, 34]. In the European validation of the Vancouver classification system, Rayan et al. found excellent intra- and interobserver reliability among medical students, surgical trainees, and senior orthopaedic surgeons [34]. Similarly, in a review of 45 radiographs of patients with periprosthetic femur fractures, Naqvi et al. found an 81% interobserver agreement with a κ value of 0.68 when classifying B1, B2, and B3 fractures [35].

Intraoperative Vancouver Classification

Intraoperative periprosthetic fractures are first defined by their location and then subclassified based on fracture type. Type A fractures are located at the proximal metaphysis, Type B fractures are located at the proximal diaphysis, and Type C fractures are distal to the tip of the femoral component. Each fracture is then assigned a subtype: Type 1 is a simple cortical breach, Type 2 is a nondisplaced fracture line, and Type 3 is a displaced fracture.

Table 7.1 Intraoperative Vancouver classification

Type	Fracture pattern
A1	Metaphysis; cortical breach
A2	Metaphysis; nondisplaced linear crack
A3	Metaphysis; displaced, unstable fracture
B1	Diaphysis; cortical breach
B2	Diaphysis; nondisplaced linear crack
B3	Diaphysis; displaced, unstable fracture
C1	Distal to stem tip; cortical breach
C2	Distal to stem tip; nondisplaced linear crack
C3	Distal to stem tip; displaced, unstable fracture

Table 7.2 Postoperative Vancouver classification

Type	Fracture pattern	Subtype	Stem	Bone stock
A	Involving the greater trochanter	AG	N/A	N/A
	Involving the lesser trochanter	AL	N/A	N/A
B	Fracture around or just below the femoral component	B1	Stable	Adequate
		B2	Unstable	Adequate
		B3	Unstable	Inadequate
C	Fracture well distal to the tip of the femoral stem	N/A	Stable	N/A

Postoperative Vancouver Classification

Type A fractures represent fractures involving the greater or lesser trochanters and are subclassified as A_G and A_L, respectively. Fractures through the greater trochanter are usually the result of particle-induced osteolysis secondary to polyethylene wear [36]. Type B fractures involve the proximal metaphysis or diaphysis around the implanted stem. Type B fractures are further classified based on the stability of the femoral component as well as the femoral bone quality. Stable fractures are classified as Type B1, unstable fractures with adequate bone quality are classified as Type B2, and unstable fractures with poor bone quality are classified as Type B3. Data from the Swedish Hip Arthroplasty Register demonstrated that more than 80% of periprosthetic fractures are Type B fractures [3]. Lindahl and colleagues reported that for Type B fractures after primary THA, approximately 25% of fractures were stable (i.e., Type B1), while approximately 75% of fractures were associated with a loose stem (i.e., Type B2 or B3) [3]. In contrast, for periprosthetic fractures occurring after revision THA, data from the Swedish Hip Arthroplasty Register found that 50% of stems were loose while 50% of stems were stable [3]. Lastly, Type C fractures occur distal to the tip of the femoral stem.

It is crucial to appropriately differentiate between Type B1 and Type B2/B3 fractures as an unstable femoral component necessitates revision arthroplasty techniques [25]. In fact, data from the Swedish Hip Arthroplasty Register demonstrated a 30% revision rate for B1 fractures treated with open reduction and internal fixation (ORIF), while there was an 18.5% revision rate for B2 fractures treated with revision arthroplasty [7]. The authors suggested that some of their B1 fractures were initially misclassified and were actually B2 fractures, in which case ORIF alone would have been an inappropriate management [7, 25, 37, 38].

A thorough history and physical exam can aid the surgeon in determining whether the femoral component is loose. Preexisting anterior thigh pain, start-up pain, pain with non-weight-bearing range of motion, or a progressive limb length discrepancy can all be signs of a loose femoral component [25]. Furthermore, radiographic signs such as femoral component subsidence, circumferential radiolucent lines in the Gruen zones, and cement mantle failure are all suggestive of a loose femoral stem [25]. Ultimately, however, femoral component stability is confirmed during intraoperative assessment, highlighting the importance of surgical planning for all possible operative scenarios.

Management

Vancouver Type A

For Type A_G fractures, when there is less than 2 cm of displacement of the greater trochanter, Marsland et al. argue that nonoperative management is sufficient due to the stabilization imparted by the tendons of the vastus lateralis and abductor musculature [38]. If nonoperative management is pursued, patients should limit active abduction to decrease the deforming forces of the abductor tendon on the greater trochanter. With significant displacement about the greater trochanter, progression of displacement on serial radiographs, or abductor musculature weakness, operative management should be considered. If there is a high suspicion of particle-induced osteolysis of the greater trochanter, the polyethylene liner should be exchanged. Surgical fixation of the greater trochanter can occur with wires, cables, or claw plates [39]. Ricci and colleagues advocate for the use of trochanteric claw plates followed by partial weight bearing with or without an abduction brace for 8–12 weeks [40].

Fractures through the lesser trochanter (Type A_L) are rare and may often be managed nonoperatively. They are generally the result of an avulsion of the lesser trochanter and do not need to be addressed unless there is significant distal extension with involvement of the medial cortex, as this could result in destabilization of the stem. If the implant is determined to be at risk of destabilization, cerclage wire fixation provides adequate implant stability [38]. Abdel et al. recommend patients avoid full weight bearing and active hip abduction for 6–12 weeks [41]. Orthopaedic surgeons should be wary of concomitant nondisplaced A_G and A_L fractures, as this pattern may be contiguous, may signify a loose femoral component, and should be treated as such.

There is minimal data reporting directly on outcomes after operative management of Type A periprosthetic fractures. Most recommendations stem from studies examining outcomes after greater trochanteric osteotomies or nonunions [42, 43]. Lindahl reported on a series of 31 cases of claw plate fixation of the greater trochanter, 8 of which were for acute fracture. The authors noted union in 28 out of 31 patients, with 3 patients going on to fibrous union [42].

Vancouver Type B1

Type B1 periprosthetic fractures occur about the femoral component and are defined by the presence of a well-fixed femoral component. In the past, these injuries were treated with nonoperative management or skeletal traction, but these techniques are no longer recommended given the significant complications associated with prolonged immobilization [44]. After transition away from nonoperative management, open reduction and internal fixation (ORIF) became a common treatment for

Vancouver Type B1 fractures [13]. Most recently, however, to minimize the soft tissue dissection that accompanies standard ORIF techniques, minimally invasive plate osteosynthesis (MIPO) techniques with standard compression plates or locking plates have gained popularity [45] (Fig. 7.1).

In an excellent review of surgical management of Type B1 injuries, Pike et al. highlighted their current recommendation for Type B1 fractures with MIPO techniques using either a compression plate or a locking plate [13] (Fig. 7.2). The use of locking plates provides surgeons with an important mechanical advantage in osteopenic bone inherent in the geriatric patient population. If the femoral bone stock is inadequate, a locked plate augmented with cortical strut allograft is used [46]. Lastly, if there is a Type B1 fracture with an ipsilateral stemmed total knee arthroplasty (TKA), a locked plate spanning the TKA and THA femoral stems should be used. Haddad et al. note that while MIPO techniques are recommended as the standard of care for most B1 fractures, transverse or short oblique fractures at the tip of the femoral stem are not appropriate to treat with plating alone [10]. In these cases, revision to a long stem femoral implant which bypasses the distal fracture line by at least two cortical diameters is a more appropriate method of treatment [47]. Postoperatively, Marino et al. recommend non-weight bearing on the affected extremity until radiographic evidence of fracture callus is present [48].

Vancouver Type B2

In Type B2 periprosthetic fractures, the fracture occurs about a loose femoral component, with adequate femoral bone stock. These fractures therefore necessitate revision arthroplasty with a long cementless femoral component which bypasses the

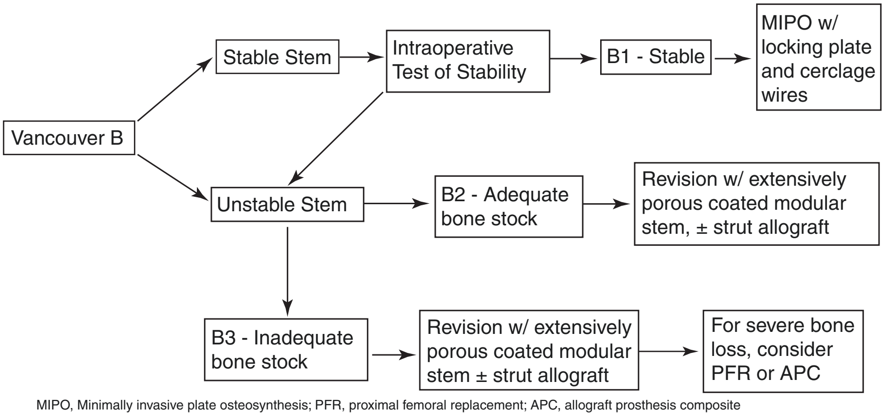

Fig. 7.1 An algorithm for Vancouver Type B periprosthetic fractures. MIPO Minimally invasive plate osteosynthesis, PFR proximal femoral replacement, APC allograft prosthesis composite

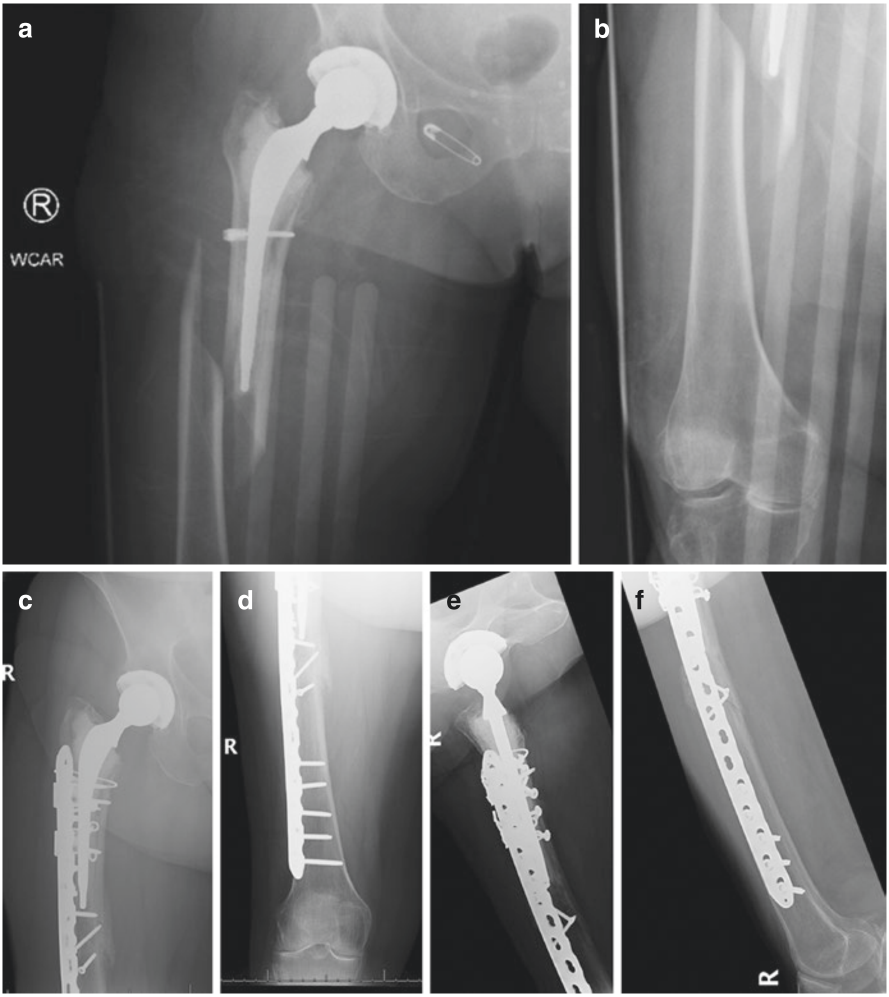

Fig. 7.2 (**a**) Anteroposterior (AP) radiograph of an 87-year-old female patient with a history of right THA demonstrating a right Vancouver Type B1 periprosthetic fracture which occurred after a ground-level fall; (**b**) AP radiograph of the right femur again demonstrating a Vancouver Type B1 periprosthetic fracture; (**c**, **d**) AP radiographs demonstrating open reduction and internal fixation (ORIF) of a Vancouver Type B1 periprosthetic fracture with a spanning plate and cerclage wires; (**e**, **f**) lateral radiographs of the same patient again demonstrating ORIF of a Vancouver Type B1 periprosthetic fracture

distal fracture line by at least two cortical diameters along with fixation of the fracture (Fig. 7.3). Given the high rate of osteoporosis in patients with periprosthetic fractures, early literature focused on the use of cemented long-stem prosthesis. However, likely due to the tendency for cement to interpose between fracture fragments and prevent union, mid- and long-term outcome studies for cemented stems demonstrated high failure rates [49].

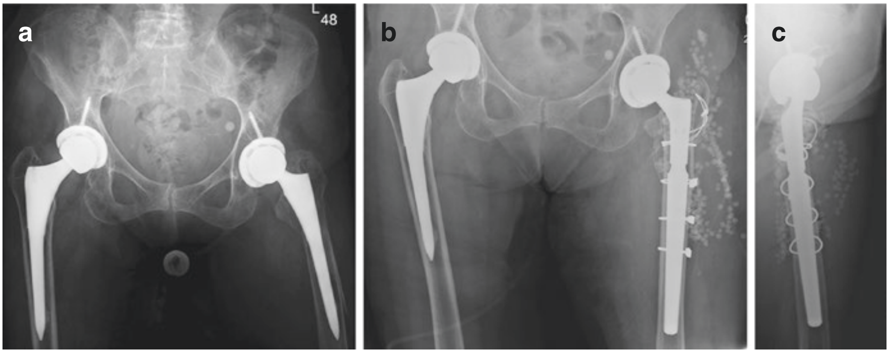

Fig. 7.3 (**a**) Anteroposterior (AP) radiograph of a 92-year-old female patient with a history of bilateral THA demonstrating a left Vancouver Type B2 periprosthetic fracture which occurred after a ground-level fall; (**b**, **c**) AP and lateral radiographs demonstrating a revision arthroplasty with a modular fluted tapered stem and cable fixation. Note an extended trochanteric osteotomy was used for removal of the index femoral component

Extensively Porous-Coated Stems

There was a period when surgeons preferred to use extensively porous-coated long-stem implants for periprosthetic femur fractures, which provide excellent distal diaphyseal fixation and demonstrate significantly improved outcomes compared to cemented stems [50]. For maximal distal interference fit, a minimum of 4–6 cm of intact distal diaphysis is recommended for femoral reconstruction prior to fracture fixation [25] when using these types of stems. If cortical bone is determined to be inadequate, cortical allograft struts are used to augment fixation and provide additional rotational stability [51]. Postoperatively, Ding et al. recommend patients be made partial weight bearing for 1–4 weeks after surgery, with progression to full weight bearing by 1–3 months, depending on the severity of the bone defect [52].

In a series of 20 patients with Type B2 fractures treated with extensively porous-coated long stems, Garcia-Rey et al. reported a 100% union rate and no thigh pain at an average follow up of 8.3 years [53]. In a review of 118 Type B fractures, Springer et al. found that extensively porous-coated stems performed significantly better with regard to survival rate and rate of nonunion as compared with proximally coated stems or cemented stems [54].

Several complications associated with extensively porous-coated stems have been described. In a review of 21 patients with Type B2 and B3 fractures treated with extensively coated steams, Sheth et al. report complications in 33% of patients including nonunion, infection, subsidence, and instability. Similarly, Garcia-Rey et al. found that 50% of patients with Vancouver B2 fractures treated with extensively porous-coated stems had subsidence of >1 cm [53]. Further, six patients (15%) were noted to have a leg-length discrepancy of >1 cm, and two patients had a discrepancy of >2 cm [53].

Modular Tapered Stems

Another option that allows for distal diaphyseal engagement in the setting of a loose femoral component (Vancouver B2), and one which has taken over as the predominant stem type used in this setting, is the modular tapered fluted stem. The tapered design of the stem allows for axial stability, while the splines allow for rotational stability of the femoral implant. The modular proximal component of these stems mates via a Morse taper and allows the surgeon to exercise greater control over limb length, offset, and femoral version. Additionally, modular tapered fluted stems can achieve stability with <4 cm of engagement with the distal diaphysis [55]. The selected implant should be of sufficient length to bypass the distal aspect of the fracture line by at least two femoral cortical diameters.

There are multiple described techniques for insertion of modular tapered stems; however, the author's preferred technique is to first reconstruct the femur and then proceed with fracture reduction. A prophylactic cable should be placed 1 cm distal to the distal aspect of the fracture line to prevent distal fracture propagation during femoral component revision. Next, manual sequential tapered reamers are used to reduce the risk of iatrogenic cortical perforation. The selected modular tapered fluted stem is then impacted into the distal femur, and trial components are used to obtain the desired limb length, stability, and version. Two to three cables or wires are then used to secure the proximal fracture fragments. Some authors choose to augment the intramedullary fixation with cortical strut grafts depending on specific fracture characteristics (i.e., transverse fracture) [56]. Postoperatively, patients may be protected weight bearing with no abduction for 4–6 weeks.

Outcomes for the use of modular fluted tapered stems in the setting of periprosthetic fracture have been largely positive. In a review of 44 patients with Type B2 and B3 fractures, Abdel et al. reported a 2% nonunion rate and a mean Harris Hip score of 83 at 4.3 year average follow-up [57]. The authors note, however, that 7 of 44 patients went on to reoperation, 5 for recurrent instability, and 2 for deep infection [57]. Similarly, Munro et al. reported on 55 patients (38 Type B2, 17 Type B3) treated with modular fluted tapered stems. At mean follow-up of 54 months, the authors found only one radiographic nonunion and two revision operations, one for subsidence and one for deep infection [55]. Additionally, the authors reported excellent patient-reported outcome scores [55]. Recently there has been interest in using non-modular titanium tapered fluted stems for periprosthetic fractures, with good short-term results reported [58].

Subsidence is the most common complication seen with the use of modular fluted tapered stems. Munro et al. noted a 24% rate of subsidence in their cohort, though only 1 patient out of 55 required revision [55]. Hernandez-Vaquero noted a 50% rate of subsidence in their cohort, with a mean subsidence of 3.9 mm [59]. The authors note that none of the patients who experience subsidence required revision surgery [59]. To combat subsidence, Patel and colleagues recommend choosing a stem that is one or two sizes bigger than the final reamer [60].

Vancouver Type B3

Type B3 fractures are defined by a loose femoral stem and severely deficient femoral bone stock. Several of the implant options used in Type B2 fractures (i.e., extensively porous-coated stems, modular tapered stems) are also used in Type B3 fractures. It is important to note that bone loss visualized intraoperatively is likely to be more severe than estimated with standard preoperative radiographs [61]. In the setting of severe bone loss extending beyond the femoral isthmus, some Type B3 fractures may not be amenable to treatment with modular tapered stems, as these constructs rely on distal diaphyseal fixation, although there have been several reports of success using this stem design for Type B3 fractures [55]. In particularly challenging cases where these are not a viable option, the surgeon has three main options: impaction grafting, replacement with an allograft-prosthesis composite (APC), or a tumor mega prosthesis such as a proximal femoral replacement (PFR).

Impaction grafting can be used to create a "neo-endosteum" and assist in diaphyseal fixation in patients with an otherwise wide femoral canal. Additionally, impaction grafting can assist in addressing fracture comminution, which is often significant with Type B3 fractures. Tsiridis et al. describe their technique wherein they impact morselized fresh-frozen allograft bone chips into the femoral canal prior to cementing their implant. The authors describe a series of 106 patients with B2 or B3 fractures and report that those treated with impaction grafting had four times the rate of radiographic union compared to those treated without impaction grafting. However, given the risk of subsidence and subsequent loosening, impaction grafting is not frequently utilized.

Allograft-prosthesis composites have fallen out of favor due to mixed clinical outcomes and the significant technical demands of the operation. Proximally, the construct consists of a long stem cemented into a proximal femur allograft. Distally, the long stem is impacted into the distal femur of the host bone. Min et al. note the 10-year survival rate of APCs to be 65–85% [62]. Maury and colleagues describe a series of 25 patients with Type B3 fractures treated with APC and report that in 20% of patients, the graft did not incorporate with host bone [63]. Additionally, the authors reported radiographic graft resorption in 6 of 25 hips [63]. Given the concerns for graft resorption, Shah et al. note that the APC is a mechanically weaker construct as compared with a tumor mega prosthesis such as a PFR [25].

A PFR can be utilized in low-demand patients with severely compromised proximal bone stock often extending to the level of the trochanters. Clinical outcomes for PFRs are mixed, and the use of a PFR should be considered a salvage operation. One of the main benefits of PFR is the lack of weight-bearing restriction in the immediate postoperative periods. This is of particular importance for the geriatric patient who would otherwise be significantly impacted by the morbidity of prolonged non-weight-bearing status. However, one of the main drawbacks of the PFR is the inability to secure soft tissue attachments proximally, leading to a high incidence of abductor weakness (consequently a Trendelenburg gait) and increased dislocation rate. Outcome studies for PFRs after Type B3 fractures are sparse and sample sizes limited. Of those published, the most common complications include dislocation, aseptic loosening, and low functional outcomes [64–66]. After PFR, options for further revision surgery are extremely limited beyond a total femur replacement.

Vancouver Type C

Type C fractures occur well distal to the tip of the femoral component and may be treated as isolated fractures (i.e., without femoral component) with closed reduction and MIPO techniques or ORIF following standard fracture fixation principles (Fig. 7.4). For Type C fractures, an important consideration is the length of the plate

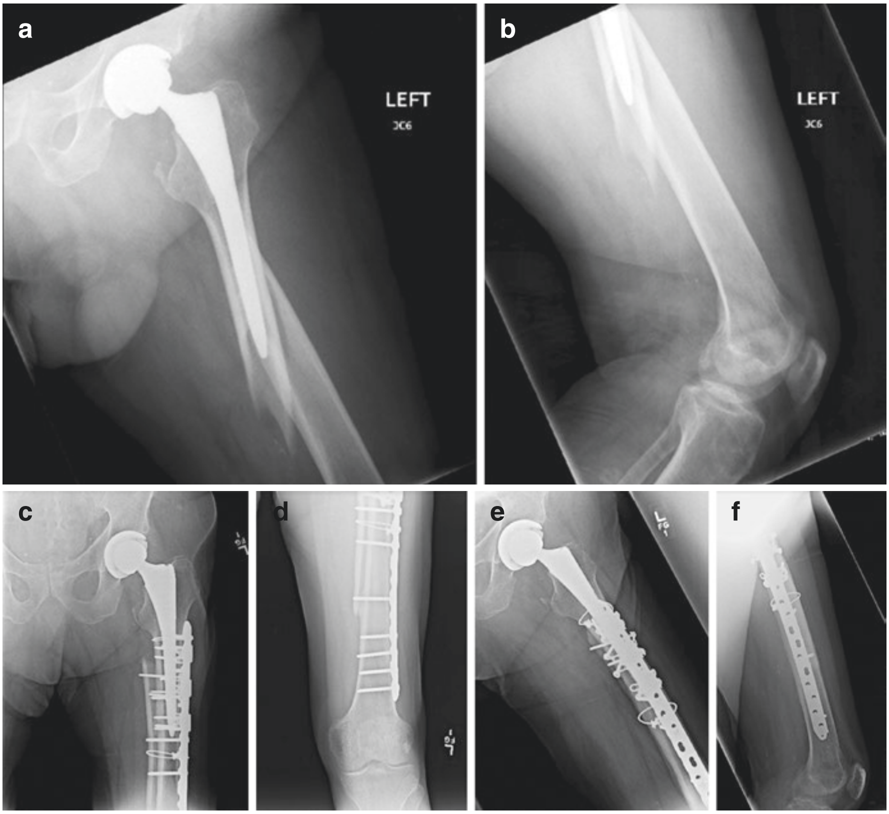

Fig. 7.4 (**a**) Anteroposterior (AP) radiograph of an 81-year-old male patient with a history of left primary THA demonstrating a Vancouver Type C periprosthetic fracture which occurred after a ground-level fall; (**b**) lateral radiograph again demonstrating a Vancouver Type C periprosthetic fracture; (**c**, **d**) AP radiographs demonstrating open reduction and internal fixation (ORIF) of a Vancouver Type C periprosthetic fracture with a spanning plate, cerclage wires, and strut allograft; (**e**, **f**) lateral radiographs of the same patient again demonstrating ORIF of a Vancouver Type C periprosthetic fracture

used to treat the fracture as it is important to not create a stress riser between the proximal aspect of the plate and the distal aspect of the femoral stem. The plate should be of sufficient length to cover two cortical diameters above the distal aspect of the stem tip while also being able to secure four to six cortices of fixation distally [67]. Almost all modern plates have the option for locking screw placement, which is useful for osteoporotic bone [40]. Unicortical locking screws, cerclage wires, or both can also assist with proximal fixation [67]. Loosen et al. note that postoperative weight-bearing restrictions following plate fixation of Type C fractures vary by surgeon, with most opting for non-weight bearing for 6 weeks [68]. O'Toole et al. describe a series of 12 patients with Type C fractures treated with lateral locking plates and report 10 of 11 patients healed without complication, while 1 patient experienced plate pullout requiring revision [67].

Given the significant potential morbidity associated with prolonged non-weight bearing in the geriatric patient population, Langenhan et al. advocate for treatment of Type B and C fractures with a novel distally locked modular prosthesis nail, irrespective of stem stability. In a review of 52 patients with Type B1/B2/B3 and Type C fractures, immediate full weight bearing seen with use of a distally locked modular prosthesis nail resulted in a significant decrease in mortality versus ORIF [69]. The authors argue that irrespective of stem stability, surgeons should consider the use of a distally locked modular prosthesis nail given the benefits of full weight bearing in the immediate postoperative period [69].

Another option for the treatment of Type C fractures includes the use of a retrograde intramedullary nail (rIMN) and lateral plate combination technique as described by Liporace and Yoon [70]. The authors advocate for the placement of a rIMN followed by a lateral plate which extends proximally to the base of the greater trochanter. The plate is linked to the nail using the perfect circle technique [70]. Using this combination construct, patients can fully bear weight on the affected extremity in the immediate postoperative period.

Outcomes and Complications

Overall, the risk of complications after periprosthetic femoral fractures is high. In a review of 1049 patients from the Swedish Hip Arthroplasty Register, Lindahl et al. report an overall complication rate of 18%, a reoperation rate of 23%, and a 1-year mortality of 9.4% [71]. Common complications from their study were bleeding (3.4%), early dislocation (3.2%), and stroke (1.0%) [71]. Additionally, the authors report a 60% rate of chronic pain seen in their surviving patient sample [71]. Bhattacharyya et al. found that 1-year mortality rate after surgical treatment of periprosthetic fracture was similar to the 1-year mortality rate seen after hip fracture (11.0% and 16.5%, respectively) [72]. Additionally, this study demonstrated a significantly higher mortality rate (11.0%) seen in patients with periprosthetic fracture as compared with age- and sex-matched patients undergoing primary THA (2.9%) [72]. Early mobilization in the geriatric patient population is of the utmost importance and can prevent some of these complications.

Conclusions

As the number of total hip arthroplasty procedures continues to rise, periprosthetic fractures present an increasingly common and complex problem for orthopaedic surgeons. Periprosthetic fracture of the femur requires the surgeon to simultaneously address bone loss, implant stability, and the fracture itself. Particularly for geriatric patients, the goal of treatment is stable fracture fixation with early mobilization. Determining femoral component stability is one of the most important aspects of management. A periprosthetic femoral fracture with a loose stem is the most common scenario. In these situations, the current literature supports treatment with an uncemented long revision stem. There are several other less commonly performed reconstruction options that surgeons may perform based on bone quality and fracture characteristics. Complication and morbidity rate after periprosthetic fracture is high, with mortality rates approaching those of hip fracture patients [73].

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References

1. Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. Lancet. 2007;370(9597):1508–19.
2. Sarvilinna R, Huhtala HSA, Sovelius RT, Halonen PJ, Nevalainen JK, Pajamäki KJK. Factors predisposing to periprosthetic fracture after hip arthroplasty: a case (n = 31)-control study. Acta Orthop Scand. 2004;75(1):16–20.
3. Lindahl H. Epidemiology of periprosthetic femur fracture around a total hip arthroplasty. Injury. 2007;38(6):651–4.
4. Berry DJ. Epidemiology: hip and knee. Orthop Clin North Am. 1999;30(2):183–90.
5. Bottle A, Griffiths R, White S, Wynn-Jones H, Aylin P, Moppett I, et al. Periprosthetic fractures: the next fragility fracture epidemic? A national observational study. BMJ Open. 2020;10(12):e042371.
6. Duwelius PJ, Schmidt AH, Kyle RF, Talbott V, Ellis TJ, Butler JBV. A prospective, modernized treatment protocol for periprosthetic femur fractures. Orthop Clin North Am. 2004;35(4):485–92. vi
7. Lindahl H, Garellick G, Regnér H, Herberts P, Malchau H. Three hundred and twenty-one periprosthetic femoral fractures. J Bone Joint Surg Am. 2006;88(6):1215–22.
8. Abdel MP, Houdek MT, Watts CD, Lewallen DG, Berry DJ. Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties: a 40-year experience. Bone Joint J. 2016;98-B(4):468–74.
9. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89(4):780–5.
10. Yasen AT, Haddad FS. Periprosthetic fractures: bespoke solutions. Bone Joint J. 2014;96-B(11 Suppl A):48–55.

11. Della Rocca GJ, Leung KS, Pape H-C. Periprosthetic fractures: epidemiology and future projections. J Orthop Trauma. 2011;25(Suppl 2):S66–70.
12. Sidler-Maier CC, Waddell JP. Incidence and predisposing factors of periprosthetic proximal femoral fractures: a literature review. Int Orthop. 2015;39(9):1673–82.
13. 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(11):677–88.
14. Moazen M, Jones AC, Jin Z, Wilcox RK, Tsiridis E. Periprosthetic fracture fixation of the femur following total hip arthroplasty: a review of biomechanical testing. Clin Biomech (Bristol, Avon). 2011;26(1):13–22.
15. Schwarzkopf R, Oni JK, Marwin SE. Total hip arthroplasty periprosthetic femoral fractures: a review of classification and current treatment. Bull Hosp Jt Dis. 2013;71(1):68–78.
16. Thien TM, Chatziagorou G, Garellick G, Furnes O, Havelin LI, Mäkelä K, et al. Periprosthetic femoral fracture within two years after total hip replacement: analysis of 437,629 operations in the nordic arthroplasty register association database. JBJS. 2014;96(19):e167.
17. Singh JA, Jensen MR, Harmsen SW, Lewallen DG. Are gender, comorbidity, and obesity risk factors for postoperative periprosthetic fractures after primary total hip arthroplasty? J Arthroplast. 2013;28(1):126–131.e2.
18. Mayle RE, Della Valle CJ. Intra-operative fractures during THA. J Bone Joint Surg. 2012;94-B(11_Supple_A):26–31.
19. Holley K, Zelken J, Padgett D, Chimento G, Yun A, Buly R. Periprosthetic fractures of the femur after hip Arthroplasty: an analysis of 99 patients. HSS J. 2007;3(2):190–7.
20. Lee S-R, Bostrom MPG. Periprosthetic fractures of the femur after total hip arthroplasty. Instr Course Lect. 2004;53:111–8.
21. 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(1 Suppl A):50–9.
22. Herndon CL, Nowell JA, Sarpong NO, Cooper HJ, Shah RP, Geller JA. Risk factors for periprosthetic femur fracture and influence of femoral fixation using the mini-anterolateral approach in primary total hip arthroplasty. J Arthroplast. 2020;35(3):774–8.
23. Tsiridis E, Haddad FS, Gie GA. The management of periprosthetic femoral fractures around hip replacements. Injury. 2003;34(2):95–105.
24. Jakubowitz E, Seeger JB, Lee C, Heisel C, Kretzer JP, Thomsen MN. Do short-stemmed-prostheses induce periprosthetic fractures earlier than standard hip stems? A biomechanical ex-vivo study of two different stem designs. Arch Orthop Trauma Surg. 2009;129(6):849–55.
25. Shah RP, Sheth NP, Gray C, Alosh H, Garino JP. Periprosthetic fractures around loose femoral components. J Am Acad Orthop Surg. 2014;22(8):482–90.
26. Cooke PH, Newman JH. Fractures of the femur in relation to cemented hip prostheses. J Bone Joint Surg Br. 1988;70(3):386–9.
27. Karnuta JM, Haeberle HS, Luu BC, Roth AL, Molloy RM, Nystrom LM, Piuzzi NS, Schaffer JL, Chen AF, Iorio R, Krebs VE, Ramkumar PN. Artificial Intelligence to Identify Arthroplasty Implants From Radiographs of the Hip. J Arthroplasty. 2021;36(7S):S290–S294.e1. https://doi.org/10.1016/j.arth.2020.11.015. Epub 2020 PMID: 33281020.
28. Chevillotte CJ, Ali MH, Trousdale RT, Larson DR, Gullerud RE, Berry DJ. Inflammatory laboratory markers in periprosthetic hip fractures. J Arthroplast. 2009;24(5):722–7.
29. Shah RP, Plummer DR, Moric M, Sporer SM, Levine BR, Della Valle CJ. Diagnosing infection in the setting of periprosthetic fractures. J Arthroplast. 2016;31(9 Suppl):140–3.
30. Duncan CP, Masri BA. Fractures of the femur after hip replacement. Instr Course Lect. 1995;44:293–304.
31. Gaski GE, Scully SP. In brief: classifications in brief: Vancouver classification of postoperative periprosthetic femur fractures. Clin Orthop Relat Res. 2011;469(5):1507–10.
32. Masri BA, Meek RMD, Duncan CP. Periprosthetic fractures evaluation and treatment. Clin Orthop Relat Res. 2004;420:80–95.
33. Brady OH, Garbuz DS, Masri BA, Duncan CP. The reliability and validity of the Vancouver classification of femoral fractures after hip replacement. J Arthroplast. 2000;15(1):59–62.

34. Rayan F, Dodd M, Haddad FS. European validation of the Vancouver classification of periprosthetic proximal femoral fractures. J Bone Joint Surg Br. 2008;90(12):1576–9.
35. 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 Arthroplast. 2012;27(6):1047–50.
36. Roffman M, Mendes DG. Fracture of the femur after total hip arthroplasty. Orthopedics. 1989;12(8):1067–70.
37. Lindahl H, Malchau H, Odén A, Garellick G. Risk factors for failure after treatment of a periprosthetic fracture of the femur. J Bone Joint Surg Br. 2006;88(1):26–30.
38. Marsland D, Mears SC. A review of periprosthetic femoral fractures associated with total hip arthroplasty. Geriatr Orthop Surg Rehabil. 2012;3(3):107–20.
39. Jarit GJ, Sathappan SS, Panchal A, Strauss E, Di Cesare PE. Fixation systems of greater trochanteric osteotomies: biomechanical and clinical outcomes. J Am Acad Orthop Surg. 2007;15(10):614–24.
40. Ricci WM. Periprosthetic femur fractures. J Orthop Trauma. 2015;29(3):130–7.
41. Abdel MP, Cottino U, Mabry TM. Management of periprosthetic femoral fractures following total hip arthroplasty: a review. Int Orthop. 2015;39(10):2005–10.
42. Lindahl H, Oden A, Garellick G, Malchau H. The excess mortality due to periprosthetic femur fracture. A study from the Swedish national hip arthroplasty register. Bone. 2007;40(5):1294–8.
43. Guidera KJ, Borrelli J, Raney E, Thompson-Rangel T, Ogden JA. Orthopaedic manifestations of Rett syndrome. J Pediatr Orthop. 1991;11(2):204–8.
44. Fredin HO, Lindberg H, Carlsson AS. Femoral fracture following hip arthroplasty. Acta Orthop Scand. 1987;58(1):20–2.
45. Sen R, Prasad P, Kumar S, Nagi O. Periprosthetic femoral fractures around well fixed implants: a simple method of fixation using LC-DCP with trochanteric purchase. Acta Orthop Belg. 2007;73(2):200–6.
46. Haddad FS, Duncan CP, Berry DJ, Lewallen DG, Gross AE, Chandler HP. Periprosthetic femoral fractures around well-fixed implants: use of cortical onlay allografts with or without a plate. J Bone Joint Surg Am. 2002;84(6):945–50.
47. Schmotzer H, Tchejeyan GH, Dall DM. Surgical management of intra- and postoperative fractures of the femur about the tip of the stem in total hip arthroplasty. J Arthroplast. 1996;11(6):709–17.
48. Marino DV, Mesko DR. Periprosthetic proximal femur fractures. In: StatPearls [internet]. Treasure Island, FL: StatPearls Publishing; 2020. [cited 2020 Dec 22]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK557559/.
49. Incavo SJ, Beard DM, Pupparo F, Ries M, Wiedel J. One-stage revision of periprosthetic fractures around loose cemented total hip arthroplasty. Am J Orthop (Belle Mead NJ). 1998;27(1):35–41.
50. Paprosky WG, Greidanus NV, Antoniou J. Minimum 10-year-results of extensively porous-coated stems in revision hip Arthroplasty. Clin Orthop Relat Res. 1999;369:230–42.
51. Canbora K, Kose O, Polat A, Aykanat F, Gorgec M. Management of Vancouver type B2 and B3 femoral periprosthetic fractures using an uncemented extensively porous-coated long femoral stem prosthesis. Eur J Orthop Surg Traumatol. 2013;23(5):545–52.
52. Ding Z, Ling T, Yuan M, Qin Y, Mou P, Wang H, et al. Minimum 8-year follow-up of revision THA with severe femoral bone defects using extensively porous-coated stems and cortical strut allografts. BMC Musculoskelet Disord [Internet]. 2020 Apr 8 [cited 2021 Feb 6];21. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7140549/.
53. García-Rey E, García-Cimbrelo E, Cruz-Pardos A, Madero R. Increase of cortical bone after a cementless long stem in periprosthetic fractures. Clin Orthop Relat Res. 2013;471(12):3912–21.
54. Springer BD, Berry DJ, Lewallen DG. Treatment of periprosthetic femoral fractures following total hip arthroplasty with femoral component revision. JBJS. 2003;85(11):2156–62.
55. Munro JT, Garbuz DS, Masri BA, Duncan CP. Tapered fluted titanium stems in the management of Vancouver B2 and B3 periprosthetic femoral fractures. Clin Orthop Relat Res. 2014;472(2):590–8.

56. Rodriguez JA, Fada R, Murphy SB, Rasquinha VJ, Ranawat CS. Two-year to five-year follow-up of femoral defects in femoral revision treated with the link MP modular stem. J Arthroplast. 2009;24(5):751–8.
57. Abdel MP, Lewallen DG, Berry DJ. Periprosthetic femur fractures treated with modular fluted, tapered stems. Clin Orthop Relat Res. 2014;472(2):599–603.
58. Clair AJ, Cizmic Z, Vigdorchik JM, Poultsides LA, Schwarzkopf R, Rathod PA, et al. Nonmodular stems are a viable alternative to modular stems in revision total hip arthroplasty. J Arthroplast. 2019;34(7):S292–6.
59. Hernandez-Vaquero D, Fernandez-Lombardia J, de los Rios JL, Perez-Coto I, Iglesias-Fernandez S. Treatment of periprosthetic femoral fractures with modular stems. Int Orthop. 2015;39(10):1933–8.
60. Patel PD, Klika AK, Murray TG, Elsharkawy KA, Krebs VE, Barsoum WK. Influence of technique with distally fixed modular stems in revision total hip arthroplasty. J Arthroplast. 2010;25(6):926–31.
61. Learmonth ID. The management of periprosthetic fractures around the femoral stem. J Bone Joint Surg. 2004;86-B(1):13–9.
62. Min L, Peng J, Duan H, Zhang W, Zhou Y, Tu C. Uncemented allograft-prosthetic composite reconstruction of the proximal femur. Indian J Orthop. 2014;48(3):289–95.
63. 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(5):953–8.
64. McLean AL, Patton JT, Moran M. Femoral replacement for salvage of periprosthetic fracture around a total hip replacement. Injury. 2012;43(7):1166–9.
65. Malkani AL, Settecerri JJ, Sim FH, Chao EY, Wallrichs SL. Long-term results of proximal femoral replacement for non-neoplastic disorders. J Bone Joint Surg Br. 1995;77(3):351–6.
66. Klein GR, Parvizi J, Rapuri V, Wolf CF, Hozack WJ, Sharkey PF, et al. Proximal femoral replacement for the treatment of periprosthetic fractures. JBJS. 2005;87(8):1777–81.
67. O'Toole RV, Gobezie R, Hwang R, Chandler AR, Smith RM, Estok DM, et al. Low complication rate of LISS for femur fractures adjacent to stable hip or knee arthroplasty. Clin Orthop Relat Res. 2006;450:203–10.
68. Loosen A, Fritz Y, Dietrich M. Surgical treatment of distal femur fractures in geriatric patients. Geriatr Orthop Surg Rehabil [Internet]. 2019 Jul 2 [cited 2021 Feb 6];10. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6607559/.
69. Langenhan R, Trobisch P, Ricart P, Probst A. Aggressive surgical treatment of periprosthetic femur fractures can reduce mortality: comparison of open reduction and internal fixation versus a modular prosthesis nail. J Orthop Trauma. 2012;26(2):80–5.
70. Liporace FA, Yoon RS. Nail plate combination technique for native and periprosthetic distal femur fractures. J Orthop Trauma. 2019;33(2):e64.
71. 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 Arthroplast. 2005;20(7):857–65.
72. Bhattacharyya T, Chang D, Meigs JB, Estok DM, Malchau H. Mortality after periprosthetic fracture of the femur. J Bone Joint Surg Am. 2007;89(12):2658–62.
73. Boddapati V, Grosso MJ, Sarpong NO, Geller JA, Cooper HJ, Shah RP. Early morbidity but not mortality increases with surgery delayed greater than 24 hours in patients with a periprosthetic fracture of the hip. J Arthroplast. 2019;34(11):2789–2792.e1.