MINI-SYMPOSIUM: REVISION HIP ARTHROPLASTY

(iv) Periprosthetic fractures of the hip

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Summary
Periprosthetic fractures are increasing in number and complexity. Appropriate precautions should be taken to prevent these fractures. A systematic approach is needed in the form of detailed assessment of the fracture, stability of the implant and the available bone stock for planning an appropriate treatment. The treatment options described in this article can be used as a framework for making the right surgical decision regarding appropriate method of reconstruction to ensure optimum result.

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Introduction
As the number of primary and revision hip joint replacements increases every year, so the number of ageing patients with joint replacements in place has been increasing steadily over the past few decades. They are frequently associated with polyethylene wear and osteolysis which predispose them to subsequent periprosthetic fractures, being seen quite frequently.

Management of these fractures is difficult, complex, expensive and may be associated with complications and pre-existing co-morbidities commonly seen in older patients.

Fractures can involve either the acetabulum or femur and can occur during primary or revision arthroplasty, or present at any time thereafter. Intraoperative fractures can be prevented by precise preoperative planning, i.e. by recognition and treatment of predisposing factors such as significant osteolysis, and by careful surgical technique.

Periprosthetic fractures of the acetabulum
There is surprisingly little reported in the literature about periprosthetic fractures of the acetabulum. They can be broadly grouped as perioperative or postoperative fractures.

Perioperative fractures
The overall incidence is not known. McElfresh and Coventry reported a 0.2% incidence among 5400 cemented hip arthroplasties at the Mayo Clinic. Nor is there a specific classification system. Callaghan in an in vitro study described various fracture patterns including anterior wall, posterior wall, inferior lip, transverse and isolated column fractures.

Intraoperative fractures of the acetabulum are commonly due to excessive undersizing of the reamed cavity and the subsequent need to use excessive force to seat an uncemented acetabular shell. Callaghan et al., in an
in vitro study reported a greater than 50% fracture rate when under-reaming was more than 4 mm and a 12% fracture rate when it was limited to 2 mm. Intraoperative fractures may also occur due to a combination of excessive reaming and shell impaction force in the presence of a very weakened or deficient acetabulum due to osteolysis or osteoporosis. Most commonly this is through the floor of the acetabulum.

Fractures recognised during surgery should be evaluated further by meticulous exposure of the fracture site. Any involvement of the columns should be identified as it affects the management. Routine use of intraoperative radiographs is not essential for this evaluation.

Prevention
During insertion of press-fit acetabular components, under-reaming should be kept to 2 mm or less particularly for smaller sizes or for patients with bone loss due to osteoporosis or osteolysis. Appropriate hemisphere reaming of the acetabulum should be performed to avoid intraoperative fractures. In osteopenic bone one should consider under-reaming by 1 mm or even not at all and the routine use of screws.

In revision cases careful reaming should be performed to avoid decreasing the bone stock further. If bone stock is to be sacrificed in order to prepare a hemispherical cavity, the posterior column and the dome should be preferentially protected at the expense of the medial wall and anterior column. Ideally as little host bone should be sacrificed as possible. In the presence of decreased bone stock, under-reaming by more than 2 mm can potentially result in pelvic discontinuity during the insertion of press-fit acetabular component and great care should be taken to avoid this potentially devastating complication.

With the increasing use of acetabular shells that have an elliptical shape (such as trabecular metal shells and surface replacement components) under-reaming is unwise as the nominal size of the component is commonly 1–2 mm less than the true rim diameter. This is particularly important to understand in the revision scenario where the surgeon is dealing with weakened bone.

Treatment
If a fracture is obvious during operation, careful evaluation of the fracture and implant stability should be made. Fractures with no involvement of the posterior column and a stable acetabular component can be treated by augmentation with screws. If the acetabular component is unstable and is associated with a posterior column fracture, buttress plating of the posterior column using a 3.5 mm pelvic reconstruction plate should be performed, in addition to augmentation of acetabular component fixation with screws.

Many of these fractures are not obvious at the time of operation. If the fracture and the implant are judged to be stable, management can be expectant, with protected weight bearing. Otherwise, they should be managed as a postoperative fracture, see below.

Postoperative fractures
The figures relating to the true incidence of these fractures are not available as very few reports exist in the literature. Berry3 reported a 0.9% prevalence (31 of 3105) of postoperative fractures with pelvic discontinuity. They can result from:

- Trauma: Traumatic postoperative periacetabular fractures are rare.
- Secondary to osteolysis which is a major predisposing factor: Periodic follow-up of arthroplasty patients is helpful to detect any progressive osteolysis. Early intervention in these cases helps to prevent their progression to periacetabular fractures.
- Stress fractures: Stress fractures of the weakened medial wall of the acetabulum can be seen after cementless revisions.4 Patients with arthritis can have preoperative osteopenia due to inactivity. These patients can have stress fractures of the pubis due to increased activity levels after hip replacement.

Peterson and Lewallen5 classified them as follows:

- Type I: Fractures associated with clinically and radiologically stable acetabular component.
- Type II: Fractures associated with unstable acetabular component.

Diagnosis
Postoperative fractures should be included in the differential diagnosis of patients presenting with acute onset of groin pain. There may not be a history of trauma especially in patients with osteolysis. Osteopenia is not uncommon in elderly patients with arthritis due to immobility. Postoperative fractures in such patients due to increased activity level after surgery should be kept in mind. One should look for pelvic discontinuity in these patients. In most cases the discontinuity represents a transverse acetabular fracture non-union (Fig. 1). Pelvic discontinuities are rare but make for very difficult reconstructions.

When postoperative fractures are detected on standard radiographs, they should be assessed further by Judet views and CT scans. The CT scans not only facilitate in fracture evaluation but also help in evaluation of the bone loss due to osteolysis and thereby assist in planning appropriate treatment. Juxta-articular insufficiency fractures can involve sacrum, ileum or rami. If they are not obviously seen on standard radiographs, isotope bone scans may be useful in alerting the surgeon.

Treatment
Fractures associated with a stable acetabular component (Type I fractures) detected during the early postoperative period can be treated conservatively with protected weight bearing for 6–8 weeks. Similar management can be done for late presenting type 1 fractures. This will allow the fracture to heal and may simplify the subsequent acetabular revision which is needed for the majority of these patients.5
These fractures are treated conservatively with activity modification until complete healing is noted, unless the injury has been so severe as to de-stabilise the acetabular component. In that instance early revision is required unless, in the case of a loosened but stable implant, it would seem the best judgment to await fracture union followed by revision.

Fractures associated with an unstable acetabular component (Type II fractures) need revision surgery. The pre-operative planning should include a detailed assessment of fracture pattern and remaining bone stock.

The goals of treatment are to provide structural integrity of the columns and to restore acetabular bone stock to provide a stable bed for the acetabular component. Isolated posterior column fractures should be fixed with a 3.5 mm pelvic reconstruction plate spanning from the ilium to the ischium (Fig. 2). Isolated anterior column fractures do not require any treatment unless they are so superior that a substantial portion of the acetabular roof is lost. In that case, treatment should be directed at restoring dome integrity using allograft or trabecular metal augments (Zimmer, Warsaw, IN). Isolated medial wall fractures or perforations do not need fixation. They can be treated by wafers of allograft combined with impacted morcellised allograft bone.

Once the fracture is dealt with, a detailed assessment of acetabular bone stock should be performed. If there is loss of less than 50% acetabular host bone, porous coated hemispherical cups can be used for reconstruction. If there is more than 50% host bone loss, one should consider the use of either the combination of trabecular metal augments and trabecular metal revision cups (Zimmer, Warsaw, IN) or reconstruction cages. The cage should span from ilium to ischium and a polyethylene cup should be cemented within it. The cage should rest on the bone inferiorly, posteriorly and superiorly to prevent its future failure; hence, this type of reconstruction should be accompanied by restoration of bone stock either by bulk or morcellised allograft. The cage not only stabilises the fracture but in addition assists in graft incorporation. Every effort should be made to plate the posterior column. If this is not possible, the inferior flange of the cage should be fixed to the surface of the ischium with screws. Bone cement

Figure 1 Pelvic discontinuity: (a) the black arrow points towards pelvic discontinuity; (b) postoperative radiograph showing reconstruction using pelvic reconstruction plate.

Figure 2 Intraoperative photograph showing reconstruction of posterior column fracture by plate.
augmentation of screw fixation may be required in these cases of much weakened bone.

Postoperative fractures due to acute trauma should be assessed and treated individually. In cases where there is intrapelvic migration of the acetabular component, one should carry out a preoperative vascular assessment and strongly consider extracting the cup from a separate ilioinguinal approach (Fig. 3).

Berry et al. reported on the treatment of patients with pelvic discontinuity by using reconstruction cages, uncemented components and cemented components without cages. Satisfactory outcome was seen in 77% of patients in the cage group and 56% of the patients in the uncemented group. None of the patients undergoing reconstruction using cemented components without a cage had a satisfactory outcome.

**Periprosthetic fractures of the femur**

Periprosthetic fractures of the femur can be broadly grouped into perioperative and postoperative fractures.

**Perioperative fractures**

These fractures can occur during primary or revision hip replacement but they tend to be more common in the revision setting. They are also more commonly associated with the use of uncemented femoral components. Berry reported a 1% prevalence (238 of 23,980) of these fractures during primary joint arthroplasty. About 71% of these fractures were associated with uncemented implants. The prevalence of these fractures was 7.8% (497 of 6349) during revision hip joint replacements. Sixty-five percent of these fractures during revision procedures were associated with the use of uncemented femoral components. Table 1 summarises the risk factors predisposing to periprosthetic femoral fractures.

Several classifications of periprosthetic femoral fractures have been described. Most are based upon the level of fracture in relation to prosthesis. Some consider the fracture pattern, type of implant (cementless versus cemented) or the timing of the fracture (intraoperative versus postoperative fractures). An ideal classification system should assist in planning the treatment and comparison of outcomes between different centres. The Vancouver classification for both intraoperative and postoperative fractures has been widely accepted in this respect.

**Intraoperative fractures**

The Vancouver classification for intraoperative fractures was described by the senior authors Masri et al. in 2004. This is based upon the level of fracture and assists in planning the treatment. Type A fractures are proximal metaphyseal in location and do not extend into the diaphysis. Type B fractures are diaphyseal but these fractures do not extend into the distal diaphysis and hence can be bypassed by a long stem revision prosthesis. Type C fractures are distal diaphyseal or metaphyseal in location and the distal extent of these fractures precludes bypassing with even the longest revision stem.

The fractures are then subdivided based upon fracture configuration and stability. Subtype 1 refers to a simple cortical perforation. These are common in the diaphyseal region (B1). These injuries tend to occur mainly during revision surgery at the time of cement removal or femoral canal preparation.

Subtype 2 refers to an undisplaced linear crack. These are common in the proximal metaphysis (A2) and in the diaphysis (B2). They tend to occur during insertion of a rasp or at the time of cementless component insertion.

Displaced or an unstable fracture pattern is designated as subtype 3. A3 fractures tend to occur during insertion of a rasp or cementless femoral component. They can also be as a result of inadvertent removal of the femoral component without clearing overhanging trochanter during revision hip surgery. B3 fractures commonly are seen during aggressive...
reaming or forceful torque applied to the lower limb either during dislocation or relocation of the hip. C3 fractures are rare but can occur during attempted forceful dislocation of the hip joint like in protrusio acetabuli.

Prevention

The incidence of periprosthetic fractures of the femur can be minimised by identifying the risk factors and addressing them appropriately. Detailed preoperative planning is an essential step in this process, which should include choice of surgical approach and of implant and back-up plans if the primary plan fails. Detailed clinical and radiographic assessment is essential. It is useful to have up-to-date radiographs as many risk factors like osteolysis and varus remodelling of the femur in revision arthroplasty setting are progressive.

Intraoperative fractures in revision surgery commonly tend to occur during dislocation, cement removal, femoral canal preparation, trial reduction and insertion of the femoral component. It is important to use finesse rather than force as undue retraction and torsional forces on the bone that has been weakened by osteolysis can lead to intraoperative fracture. Dislocation of the hip should ideally use minimal force after adequate soft tissue release has been performed. It is wise to leave previous implants like plates and screws until the dislocation has been done to prevent any stress risers.

Trochanteric overhang, if present, should be corrected by adequate clearance of overhanging bone before attempting to extract the femoral stem to avoid intraoperative trochanteric fracture. During revision of a femoral stem, an extended trochanteric ostectomy (ETO) facilitates the exposure. In addition, it assists in easy cement removal and reduces the risk of cortical perforation. Use of a guide wire and intraoperative radiographs help to avoid cortical perforation during revision surgery.

Under-reaming can be dangerous especially in osteopenic bone as it can result in fracture while using long uncemented stems. We recommend under-reaming by 0.5 mm for diaphyseal fitting stems unless a bowed stem is to be used, in which case, so-called line-to-line reaming is preferred. If the bone is weak, prophylactic cerclage wires can be used to prevent fractures. Although use of uncemented stems in the revision setting has been shown to be associated with an increased incidence of fractures, no difference has been noted regardless of whether a straight or a bowed stem is used. Furthermore, the presence of an intraoperative fracture during revision total hip arthroplasty with a fully porous-coated cementless stem has not been shown to affect the final functional outcome.10

Periodic clinical and radiological review of patients after joint replacement helps to identify progressive osteolysis. Early intervention in these patients can prevent postoperative femoral fractures.

Treatment of intraoperative fractures

The aim is to achieve near-anatomic fracture fixation and stable fixation of the prosthesis. The treatment depends not only upon the fracture location and configuration, but also upon the stability of the femoral component. Meticulous exposure of the fracture is vital, and the Vancouver classification system described earlier in this article aids in the management of these fractures.

Type A intraoperative fractures (proximal metaphyseal)
Type A1: cortical perforation. These injuries are unlikely to compromise the fixation of the prosthesis or increase the risk of postoperative fractures. They can be managed by application of locally harvested autografts, such as from acetabular reaming or can even be ignored.

Type A2: undisplaced linear crack. These fractures are best treated by cerclage wires, performed as soon as the crack is noted and before the insertion of the final femoral component. If a proximally coated stem is used, its stability should be assessed carefully and if the fracture has compromised implant stability, it should be replaced with a fully porous-coated stem. If a cemented stem is used, any cement extruded within the crack should be removed. These fractures, once stabilised do not compromise the final outcome.

Type A3: displaced fractures of the proximal femur. These fractures tend to compromise the fixation of standard femoral components, especially if they are proximally coated stems. These fractures need to be exposed and secured appropriately with cerclage wires. Diaphyseal fitting cementless stems should be used in the treatment of these fractures. Displaced fractures of the greater trochanter should be secured using cerclage wires or other trochanteric fixation devices.

Displaced fractures of the greater trochanter can be associated with ETO employed during revision arthroplasty setting. Such fractures typically occur when the osteotomised fragment is being reapproximated with a cerclage wire. As a diaphyseal fitting stem is commonly used in this setting, the fracture fragments need to be just approximated, overlapped by a cortical allograft strut and secured with cerclage wires onto the prosthesis. In addition, the trochanteric fragment needs to be stabilised by using one of the methods described above. However, this fracture can be prevented using a cortical strut graft placed under the cerclage wire to dissipate the focal forces.

Type B intraoperative fractures (diaphyseal)
Type B1: diaphyseal cortical perforation. These fractures act as stress risers and should be treated aggressively. They can be managed by bypassing the perforation with a longer stem by at least two cortical diameters. Cerclage wire applied at or just distal to the perforation prior to the insertion of the stem will prevent crack propagation. If the perforation is at the tip of the longest cementless stem it should be treated by application of an allograft strut.

Type B2: undisplaced linear fracture. These fractures should be fixed by cerclage wires and bypassed with a longer cementless stem. If this is not possible, one should use cortical onlay graft with cerclage wires to secure the fixation. If these fractures are detected postoperatively, one should consider protected weight bearing for 6–12 weeks to allow the fracture to heal.

Type B3: displaced fracture of the mid femur. These fractures should be stabilised by meticulous open reduction
and internal fixation. Long oblique or spiral fractures can be treated by cerclage wires. However, comminuted fractures need to be reinforced with one or two cortical struts. The fracture should be bypassed with a long cementless stem by at least two cortical diameters. When these fractures occur distal to a well-fixed cementless femoral component and the stem is difficult to extract without compromising the bone stock, they can be managed by application of cortical onlay grafts and cerclage wires.

**Type C intraoperative fractures (distal diaphyseal/metaphyseal)**

By definition, this fracture cannot be bypassed by the longest revision stem. C1 (cortical perforation) and C2 (linear crack) fractures tend to act as significant stress risers and hence need treatment in the form of cortical struts and cerclage wires. It is important to overlap the tip of the prosthesis with cortical struts to avoid any stress riser. The displaced (C3) fractures can be treated by the same technique or by using plate and strut fixation.

**Fractures diagnosed in the immediate postoperative period**

Complex fractures are rarely diagnosed during the immediate postoperative period as they are almost always detected at the time of surgery. If seen on the postoperative radiograph, they should be treated by reoperation and the application of the same principles as described earlier. It is more common to see undisplaced fractures during the immediate postoperative period. These fractures should be imaged carefully to define the whole extent of the fracture. Non-operative treatment in the form of protected weight bearing for 6–12 weeks suffices in most cases without any compromise of the final outcome.

**Postoperative fractures**

The prevalence of postoperative fractures in the literature ranges from 0.1% to 2.1%. The largest series from the Mayo Clinic joint registry reports a prevalence of 1.1% (262 of 23,980) in primary arthroplasty and 4% (252 of 6349) in the revision setting. The most common cause of these fractures is often an episode of minor trauma. Beals and Tower reported minor trauma as a cause of 84% of the fractures (72 of 86). Only 8% of the fractures in their series were due to major trauma.

Incidence of these fractures is expected to increase due to the increasing numbers of patients with hip replacements, and a growing number of them with compromised bone around the component due to osteolysis or revision procedures. Additionally, with ageing, these patients are at increased risk of falling.

**Classification**

Duncan and Masri published the Vancouver classification for postoperative fractures in 1995 based upon three important factors in the management; fracture location, stability of the implant and the quality of the femoral bone stock. This classification is widely accepted and has been shown to be both reliable and valid.

It has three main categories A, B and C based upon the fracture location. Type A fractures occur in the peritrochanteric region and are subdivided based upon the involvement of either the greater trochanter (A4) or lesser trochanter (type A5).

Type B fractures occur around the stem or just distal to the tip of the prosthesis. Type B fractures are subdivided into three categories based upon stability of the prosthesis and quality of the bone stock. Subtype B1 represents fractures associated with well fixed femoral components (Fig. 4). Fractures with loose femoral components are

![Figure 4 B1 fracture: (a) ununited B1 fracture, treated earlier by combination of strut graft and cable grips; (b) follow-up radiograph showing successful treatment by using cable-plate fixation.](image-url)
classed as subtype B2 (Fig. 5). B3 subtype includes fractures with severe femoral bone stock deficiency due to osteolysis or severe comminution or generalised osteopenia (Fig. 6). B3 fractures are commonly associated with a loose femoral component. At times the distinction between B2 and B3 fractures can only be done at the time of surgery.

Type C fractures are located well distal to the tip of the prosthesis.

The original article reported 75 patients with periprosthetic femoral fractures, wherein 4% of the fractures were type A, 86.7% were type B, and 9.3% were type C. Type B included 18.5% B1 fractures, 44.6% B2 fractures and 36.9% fractures.

Treatment of postoperative fractures

The possibility of infection should always be considered while treating periprosthetic fractures of the femur. The presence of a fracture makes measurement of serological markers such as the ESR and C-reactive protein potentially unreliable. Thus if suspicion of a pre-existing covert infection is high based on the wound history from the last procedure, constitutional symptoms, local physical findings or radiographic parameters, diagnosis is made by performing an aspiration biopsy of the periprosthetic space. If this confirms infection, one should consider two-stage exchange method using an intermediate articulated antibiotic loaded spacer like PROSTALAC (DePuy, Warsaw, IN) to control the infection and to stabilise the fracture.

Non-operative treatment

We no longer advocate prolonged recumbence with traction or cast immobilisation due to associated complications such as atelectasis, pneumonia, pressure sores, thrombo-embolic disease, joint stiffness and disuse osteoporosis. Additionally, non-surgical treatment is commonly associated with mal-union and non-union, making for increased technical difficulty during the next procedure. We recommend non-surgical treatment only for undisplaced fractures with stable prostheses. Such patients can be treated with protected weight bearing and/or functional bracing as required. Patients with stable A and postoperative fractures are ideal for non-operative care. We would only rarely propose non-operative management for a C type fracture.

Principles of operative treatment

The Vancouver classification facilitates preoperative planning. Routine antibiotic and deep vein thrombosis prophylaxis is essential.

The treating surgeon should be well versed in extensile approaches to the hip joint. Adequate exposure of the fracture is essential. However, intraoperative tissue specimens should be obtained for culture and antibiotics should be withheld until this step has been completed. Separation of the fracture fragments can aid in removal of cement debris from the canal and also canal preparation required for revision stem insertion. Judicious use of intraoperative radiographs may be helpful.

Methods of operative treatment

There are three broad generic approaches to treatment

- fracture fixation alone
- fixation combined with revision replacement
- complex reconstruction such as modified impaction grafting or proximal femoral replacement.
There is no single approach that is applicable to all cases. We will discuss each treatment option in detail followed by a treatment algorithm based upon the Vancouver classification.

**Cerclage wire fixation**

Monofilament wire or braided cable used as cerclage fixation can be considered for the fixation of long oblique or spiral fractures around a well-fixed prosthesis. However, on its own, this is biomechanically weak and does not provide the torsional or bending rigidity needed to reliably prevent fracture displacement. The exception is the management of a linear crack in the proximal femur occurring during insertion of the femoral component. The technique can also be used to reinforce the femur to prevent initiation or propagation of such cracks during canal preparation. Cerclage fixation is usually combined with a plate or a strut graft to provide a more rigid construct.

**Plating**

Internal fixation with plates is indicated in diaphyseal fractures that occur around well-fixed implants (Vancouver B1 fractures and Vancouver type C fractures (distal diaphyseal–metaphyseal)). As varus alignment of the stem is a contraindication for plate fixation, it is prudent to ensure that the prosthesis is in neutral alignment. The plate...
should always overlap the intramedullary stem to prevent a stress riser between the two. It is also desirable to have fixation of a minimum eight cortices screw fixation on either side of the fracture to obtain a rigid reconstruction. It is often difficult in B1 fractures to achieve this with ease due to the presence of a canal filling cementless stem or the fear of violating the cement mantle in cemented implants. Options might include directing the screws posteriorly into the thicker bone underneath the linea aspera or using unicortical screws.

To address the difficulties encountered in the proximal fixation, various cable plate designs (Ogden plate, Dall-Miles cable-plate system, etc.) have been introduced. These use cerclage fixation for the portion of the plate that spans the stem. The wires can either be locked into the plate itself or by a crimping sleeve after adequate tensioning using a special tensioning device. Holes in plates allow additional screw placement of adequate length proximally as allowed by the prosthesis and bicortical screws distal to the tip of the stem.

Dennis et al.\textsuperscript{14} compared five different options for plate fixation about femoral stems: plate with cable only, plate with proximal cable and distal bicortical screws, plate with proximal cable plus unicortical screws and distal bicortical screws, plate with proximal unicortical screws and distal bicortical screws and two allograft struts fixed with cables. These specimens were tested in torsion, lateral bending and axial compression. The constructs with proximal unicortical screws (with or without cerclage wires) were more stable than other constructs.

Figure 7 B1 fracture: (a) B1 postoperative fracture around an uncemented femoral component; (b) fixation using Locking plate (Combi plate).

Locking screw plates have been recently introduced for the fixation of periprosthetic femoral fractures (Fig. 7).\textsuperscript{15} These plates act as internal–external splints and are especially useful in the presence of osteoporotic bone. The fact that unicortical screws can provide adequate stability in this construct helps in fixation proximal to the fracture around the intramedullary stem. The forces are distributed over the whole plate increasing the pull-out strength of each screw. As they do not rely on the compression between the plate and the underlying bone, the periosteal vascular supply is least disturbed. They act as fixed-angle constructs and thereby improve the angular stability of the fracture. The modern designs with combination holes allow either fixed-angle locking screws or standard unicortical or bicortical compression screws, an important feature proximally where a large intramedullary stem can be avoided by angling the standard unicortical or bicortical screws.

**MIPO: Minimally invasive plate osteosynthesis**

This involves the least biological disturbance to the fracture site.\textsuperscript{16} In traditional open reduction, wide exposure of the fracture site results in evacuation of the fracture hematoma and stripping of the periosteum and soft tissue attachments to the fracture fragments which disturbs the local vascular supply to the fracture fragments and can have a negative influence on fracture healing. MIPO involves indirect reduction of the fracture by using a fracture table and an image intensifier. A standard or a locking plate is inserted by placing a small incision distal or proximal to the fracture and advanced submuscularly to span the fracture.
site. The screws are commonly inserted through stab wounds with image intensifier guidance. This technique can be used in fractures with large areas of comminution or long oblique fractures or spiral fractures where the bending forces through the fracture tend to be over a large area.  

Ricci et al., 17 reviewed 41 Vancouver B1 fractures treated by open reduction using indirect reduction techniques and internal fixation with single lateral plate fixation at an average follow up of 24 months. They did not use cortical strut grafts to supplement the fixation. All the patients had satisfactory fracture union at an average period of 12 weeks without any evidence of implant loosening or malalignment. They concluded that care in preserving the soft tissue envelope around the fracture by the minimally invasive techniques led to consistent healing times.

**Cortical allograft struts**

Cortical struts are generally obtained from freeze-dried femurs or tibias. They have the ability to augment the strength and stability of the construct and can be appropriately prepared to custom-fit any femur. As the modulus of elasticity of cortical struts is similar to host bone there is less stress shielding of the host bone in comparison to rigid fixation with devices like plates. 18 They can be used alone as a biological bone plate, used to augment fixation with a metal plate or can be used to augment the junction between host bone and a massive structural allograft.

Attention to some of the technical details is important to attain adequate reconstruction with cortical struts. We routinely use two allograft struts if no plate is used. However, a single allograft strut is used when augmenting fracture fixation with a plate. We ream the medullary canal of the allograft (femur or tibia) before sectioning it, until it is large enough to gain snug fixation over the host femur. We fashion each strut to about 16 cm in length and one third the circumference of the host femur. The two struts can be placed parallel to each other over medial and lateral surfaces of the femur or they can be placed perpendicular to each other over anterior and lateral surfaces of the host femur. We prefer the latter method as it entails less soft tissue stripping in comparison to the parallel technique. It is important to avoid edge contact between the two struts to prevent dissipation of the compressive force generated by the cerclage cables between the struts and thereby decreasing the stability of the construct. Three or four evenly spaced 2 mm multifilament cables should be passed around the host femur on either side of the fracture prior to positioning the struts. Morcellised allograft is generally packed within the medullary cavity of the strut before applying it on to the host femur. Central cables should be tightened first followed by peripheral cables to avoid displacement of the struts. Excessive tensioning should be avoided as it may fracture the allograft. Adequate soft tissue cover of the construct should be obtained with vastus lateralis muscle.

The strength of the construct by using cortical struts and cables has been investigated by various authors. In a biomechanical study from our centre, Haddad et al. 19 reported the effect of number of cables, cable tension, cable versus wires, strut configuration and strut length over the rigidity of the construct. They concluded that at least three or more cables should be used on both sides of the fracture, the cable tension should be high, cables instead of wires should be used and that two struts should be used. They also reported that the strut length was inversely proportional to the rigidity of the construct.

The advantages of cortical struts include their ability to heal to the host bone and remodel over time thereby increasing bone stock. The disadvantages include the prolonged time required for graft incorporation during which they are prone to stress fracture or loosening. They can also be a potential source of infection. Maximal weakness of these struts occurs between 4 and 6 months. Emerson et al. 20 analysed 63 struts that had sufficient serial radiographs. They reported 96.6% union rate at 8.4 months.

Cortical allografts have been used in combination with plates. A biomechanical study 21 from our unit investigated different methods of fixation of a B1 fracture model using, lateral plate and anterior allograft, lateral plate fixation alone and lateral and anterior allograft struts. The results showed that the rotational and translational stability was highest in strut-plate combination constructs. In a multicentre study, Haddard et al. 18 reported a 98% fracture union rate among 40 B1 postoperative periprosthetic femoral fractures patients treated by cortical strut grafts alone (19 patients) or combination of cortical strut graft and plate (21 patients). They concluded that the cortical strut grafts should be used routinely to augment fixation and healing of a periprosthetic femoral fracture.

**Revision hip arthroplasty**

Revision hip arthroplasty is the technique of choice when a fracture is associated with a loose femoral component. Long cementless stems with distal fixation to bypass the fracture by at least two cortical diameters with or without cortical strut grafting is our method of choice. Adequate exposure of the fracture site to access the femoral canal for canal debridement and preparation minimises soft tissue stripping. The use of a long cemented stem may be appropriate in the frail elderly patient with limited functional demands and lifespan, with poor bone stock and a simple fracture pattern. Every effort should be made to limit the ingress of cement into the fracture interface, and morcellised bone should be packed around the fracture site.

Modular cementless stems or extensively porous-coated cylindrical implants are used frequently to obtain distal fixation. The remaining proximal bone is usually overlapped onto the prosthesis and augmented with cortical struts. Distally fixed cementless prostheses have been successfully used in Vancouver type B2 and B3 fractures. Berry 22 in his series of seven B3 fractures treated by modular, tapered and distally fluted stems reported that, at short-term follow-up of 1.5 years all the patients had fracture union and stable implants.

**Proximal femoral replacement**

This technique using a segmental allograft femur or a tumour-type proximal femoral replacement is reserved for post-
operative Vancouver B3 fractures associated with severe, segmental bone loss. Elderly patients with limited life expectancy and associated poor bone stock can be treated by a tumor-type proximal femoral replacement prosthesis (Fig. 8). We no longer resect the proximal femur but bi-valve it (usually in the sagittal plane) and wrap it around the femoral component during closure. This facilitates reattachment of the greater trochanter and abductors as well as quadriceps function. This allows early mobilisation which is of paramount importance in this group of patients. However, in physiologically younger patients allograft-prosthesis composite is desirable for obvious reasons. Wong and Gross23 have reported the use of this technique in 19 patients with B3 fractures. Thirteen patients of the 15 available for review at a mean follow-up of 5 years had a good result. It is notable that the use of segmental proximal femoral placements has declined in North America since the introduction of more sophisticated femoral components with multimodularity and improved fatigue resistance.

Postoperative management

Postoperative management should be individualised, based upon the method of reconstruction used. Protected weight bearing is often advised for a period of 6–12 weeks until clinical and radiological union at the fracture site is obtained.

Treatment algorithm for postoperative periprosthetic femoral fractures

This algorithm is based upon the Vancouver classification system for postoperative fractures (Fig. 9).

Type A postoperative fractures

Type A fractures are generally stable and they can be treated by protected weight bearing for 6–12 weeks. Active abduction is also avoided during this period. If the displacement of the fracture is greater than 2.5 cm, one should consider internal fixation. We prefer claw grip and cables over isolated monofilament wire fixation. If the fracture is secondary to severe osteolysis, the source of the osteolysis is addressed by liner exchange or cup revision in addition to managing the fracture. It is often impossible to fix these fractures associated with severe osteolysis. During operation, attempts should be made to preserve the soft tissue envelope of the abductors and the vasti as a single sleeve of tissue because it is a valuable fracture stabiliser in these cases24 and augments blood supply at the fracture site. Use of the trochanteric slide for exposure of the hip should be considered.25 Small cortical windows aid in bone grafting of these defects.

Type A fractures are usually minor and do not need surgical intervention. If they are major and involving the calcar femorale, they can affect implant stability due to lack of medial support, hence one should consider fixation using cerclage wires.

Type B1 postoperative fractures

If possible, we currently prefer fixation using minimally invasive plate osteosynthesis techniques to preserve local vascularity. If closed reduction of the fracture is not possible, we consider open reduction and internal fixation using a lateral plate and often anterior cortical strut allograft or two cortical strut grafts placed perpendicular to each other on anterior and lateral surfaces. We do not revise the stem unless it is in varus malalignment as this might result in treatment failure.

Type B2 postoperative fractures

We prefer to use long cementless femoral stems to bypass the fracture by at least two cortical diameters. Long cemented stems can also be used in older patients with due care to avoid extrusion of cement into the fracture site. We prefer to augment the fixation with a cortical allograft strut in the presence of unstable transverse fractures. This is often not necessary while treating long oblique or spiral fracture configurations as cerclage wires can provide adequate rotational stability.

Type B3 postoperative fractures

If the bone deficiency is not severe and there is some remaining supportive proximal femur, we prefer to use modular cementless tapered femoral components along with cortical struts. However if the deficiency is severe, segmental and not reconstructable, we prefer to use a segmental allograft/prosthesis composite in young patients and a tumor-type proximal femoral replacement prosthesis in low demand elderly patients.
Type C postoperative fractures
These fractures are treated with standard fracture fixation techniques employed in the treatment of distal femoral fractures. Minimally invasive plate osteosynthesis or bridge plating can be employed in the treatment of these fractures. It is important not to leave a short segment of bone between the plate and the tip of the femoral component above as it can act as a significant stress riser and predispose to later fracture.

Conclusion
Periprosthetic fractures are increasing in number and complexity. Appropriate precautions should be taken to prevent these fractures. A systematic approach is needed in the form of detailed assessment of the fracture, stability of the implant and the available bone stock for planning an appropriate treatment. The treatment options described in this article can be used as a framework for making the right surgical decision regarding appropriate method of reconstruction to ensure optimum result.

References


