CLINICAL ARTICLE

Periprosthetic fractures of the femur associated with hip arthroplasty

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Abstract

Periprosthetic fractures following total hip or knee arthroplasty have become more common as the indications and age distribution for these procedures have increased in the last few years. Revision surgery in these patients holds a very high complication rate and therefore measures should be taken to prevent these fractures. Osteolysis with subsequent component loosening has been shown to pose a risk for periprosthetic fractures. Regular follow-up visits could reveal early signs and symptoms of component loosening. Patients who develop loosening should be revised as soon as possible to prevent periprosthetic fractures. The Vancouver classification (intra- and post-operative) for periprosthetic fractures associated with total hip replacement has been shown to be reproducible and an excellent guideline for management. Revision surgery for periprosthetic fractures carries a significant risk for complications.

This review and instructional article will focus mainly on periprosthetic fractures in hip arthroplasty, although some risk factors and biomechanical considerations are also applicable for periprosthetic fractures of the femur in knee arthroplasty. Greater trochanteric fractures can present intra-operatively or post-operatively. Non-unions of the greater trochanter commonly presents many years down the line in patients where the surgical approach was done through greater trochanteric osteotomy, and are generally difficult to treat. This review will cover some aspects on the fixation methods of these fractures. Finally the hardware and surgical adjuncts to treat periprosthetic fractures will be discussed briefly. The more common fracture patterns (type B2) and the problematic (type B3) will be discussed in more detail.

Key words:
Periprosthetic fracture, hip, Vancouver classification, revision surgery, femur

Epidemiology

Periprosthetic fractures in arthroplasty are a rare complication, but figures show a rise in the incidence over the last few years.[1-3] Total hip replacement (THR) has been shown to be a very successful treatment modality and has gained popularity all over the world, resulting in a growing spectrum of indications.[2,3] As a result, both younger and very old patients have become candidates for arthroplasty. As the younger group of patients (potentially) get more exposed to high impact trauma and the very old have the tendency towards severe osteolysis, it seems inevitable that periprosthetic fracture incidence will increase.[3] The incidence of intra-operative periprosthetic femoral fractures in THR is 0.1 to 5.4%.[2,3] This is notably higher in revision surgery, varying between 3 and 20%.[1-3] In the post-operative group trauma is the most common cause for periprosthetic fractures.[4] The incidence of post-operative periprosthetic femoral fractures following THR in the Swedish hip register was less than 0.5% of primary cases and just over 2% for revised cases.[3] The risk of supracondylar periprosthetic femoral fractures in total knee arthroplasty varies between 0.3 and 2.5%.[5]

The problem with periprosthetic fractures in arthroplasty surgery is the high complication risk of revision surgery. Revision surgery following a periprosthetic fracture poses a risk of serious complications in up to 18% of patients, with non-union, aseptic loosening and refracture being the most frequent complications.[3] Complications following periprosthetic revision surgery for the knee vary between 25 and 75%, with conservative treatment-related complications associated with similar high complication rates.[6,7]

Preventing this dire complication in arthroplasty is far better than any modality of treating it.

Risk factors associated with periprosthetic fractures

Revision surgery (for any indication), cementless press-fit techniques, osteoporotic bone, impaction bone grafting and prosthetic loosening have all been associated with periprosthetic fractures and pose a risk in the intra-operative or post-operative phase.[1,2,4]

Similarly these risk factors are relevant in total knee arthroplasty. Additionally risk factors such as rheumatoid arthritis, anterior femoral notching (anterior femoral bone cut) and rotational constrained prostheses have been associated with periprosthetic fractures in total knee arthroplasty (TKA).[4-9]

Biomechanical considerations

Femoral notching

With regards to total knee replacement (TKR) it has been shown that 3 mm notching of the anterior femoral cortex results in 30% reduction in torsional strength of the supracondylar region.[4-6] It is not surprising then that up to 50% of periprosthetic fractures in TKR are associated with anterior femoral notching.[10] However, recent contradicting data by Ritter *et al*[11] have shown that femoral notching is not associated with increased supracondylar fractures.

Stress risers and prosthetic loosening

It has been shown that a distal part of a prosthesis that has become loose theoretically becomes a stress riser.[12] However, a well-fixated stem will have no stress rising effect at its tip.[12] This idea was further supported by a study of Beals and Tower[13] who showed that the average time between insertion and fracture in cementless prostheses is six months versus 6.6 years for cemented implants, suggesting that cementless prostheses are taking a longer time to become solidly incorporated in bone (with the potential stress riser effect at its tip initially) when compared to the immediately fixed cemented prostheses. In their long-term, retrospective analysis of the Swedish hip arthroplasty register, Lindahl *et al*[3] showed that up to 70% of periprosthetic fractures showed loosening at the time of the fracture.[3] Therefore, from a biomechanical point of view, loosening (causing a stress riser effect) poses a major risk factor for periprosthetic fractures.

Revision surgery following a periprosthetic fracture poses a risk of serious complications in up to 18% of patients and preventing this dire complication in arthroplasty is far better than any modality of treating it

Considerations in fracture fixationand bone healing

When considering a femoral fracture in the region of an intramedullary prosthesis (cemented or uncemented femoral stem) in total hip arthroplasty (THA), the following differences in bone healing and osteosynthesis should be considered: Bone healing is altered due to changed local orthobiologics. Periprosthetic osteolysis and loosening affect the normal bone-healing environment.[14] Histologically, loosening is associated with granuloma formation which in part plays a role in T-cell and cytokine-driven osteolysis. Endosteal blood supply is altered to some extent with press-fit or cemented prostheses. The contribution of the periosteum in bone healing might be reduced in revised cases where periosteum was stripped to fit plates or strut grafts. It is therefore evident that the milieu, in which bone healing should take place in periprosthetic fractures, is severely compromised.

Conventional principles in osteosynthesis do not always apply considering that commonly the main methods of fixing plate to the bone are unicortical screws, osteopaenic bone or cabling. Bone cortical thickness has an important effect in tensile stress distribution. Therefore patients with a typical Dorr C shaft with thin cortices and wide medulla will not have the same resistance to bending, shearing, torsional and loading forces. This principle is important in periprosthetic salvage surgery mandating the use of cortical strut grafts to reduce peak stresses.[12]

Intra-operative and post-operative periprosthetic fractures of the femur in THA: Diagnosis, classification and management

Introduction

Periprosthetic fractures of the hip consist of two entities: intra-operative fractures, which are diagnosed and managed on the surgical table; and post-operative fractures, which are diagnosed radiologically after a clinical suspicion.

The Vancouver classification scheme, as modified by Duncan and Masri,[14] is widely used. This classification system has been validated by Brady *et al*[15] as a reliable classification system which can be used to guide treatment and suggest the patient's prognosis. The classification scheme approaches intra-operative and post-operative fractures separately. Intra-operatively the diagnosis is made clinically and the intra-operative diagnosis is based on the position and size of the type of fracture (cortical perforation, non-displaced linear crack or displaced/unstable fracture).

Intra-operative fractures of the femur in THR *(Table I)*

Treatment principles for intra-operative diagnosed periprosthetic fractures

1. The management is based on the position of the fracture and the extent of the fracture (cortical perforation, linear crack or displaced fracture).
2. The metaphyseal (type A fractures) management relies on prevention of propagation of fracture (cerclage wires or cables) or isolated fixation of the greater trochanter. The diaphyseal (type B) fractures need to be bypassed with a longer stem with or without further stabilisation with a strut or a plate.
3. Type B1 fractures (cortical perforation) are generally treated by bypassing the defect with a longer stem, which has been demonstrated to restore stability.[17]
4. All the fractures that stretch beyond the longest revision stem need to fixed and reinforced with a cortical strut graft or a plate.
5. It is therefore pivotal that these fixation modalities should always be available when any form of hip arthroplasty is performed.

The intra-operative diagnosis is based on the position and size of the type of fracture

Post-operative fractures of the femur in THR *(Table II)*

Management principles

Due to the very high complication rate in both conservative and surgical management, a multi-disciplinary team in a dedicated specialised unit will contribute to a better outcome. Additionally the arthroplasty surgeon should have experience in revision and trauma surgery.

Diagnosis

A good history, clinical examination and a radiological workup is important. The type of fracture, and systemic and local host factors should all be considered to direct the surgeon to the optimal treatment plan. The following points are important to consider in the history and clinical examination and should be documented as part of the clinical notes prior to the surgery:

1. Loosening of the prosthesis precedes many periprosthetic fractures and therefore symptoms suggestive of loosening, such as constant thigh pain or start-up pain after getting up from sitting, should be documented. This will influence the choice of treatment.
2. Onset of pain: Differentiate between a traumatic event (with emphasis on the mechanism of injury) and whether the pain had a non-traumatic spontaneous onset.
3. The presence of a leg length discrepancy prior to fracture is important to document, especially for medico-legal purposes.
4. Every patient should be carefully examined for any neurological or vascular compromise.
5. The bearing surfaces and type of implant should be documented.
6. Any stigmata of peri-operative infection should be very carefully investigated in the history. Any history of prolonged wound healing, draining sinuses, or repetitive antibiotic use should alert the surgeon to previous infection.
7. The approach of the primary surgery should be considered in the planning of the surgery.

A minimum of two views will identify most fractures, longitudinal splits and signs of component loosening. However, the component might obscure small linear cracks.

Bone scans might play a role in identifying fractures that are not visualised on radiographs. However bone scans might show increased uptake for up to two years post-operatively in the absence of a fracture.[4]

Table I: Vancouver classification for intra-operative periprosthetic fractures of the femur associated with THR modified by Duncan and Masri *(Diagram 1)*[16]

Type of fracture	Characteristics	Management options
Type A	**Proximal metaphysis, not extending into diaphysis**	
A1	Cortical perforation	Ignore if no effect on component stability. Alternatively bone graft (acetabular reamings)
A2	Non-displaced linear crack	Cerclage wiring. May need to back out cementless stem first, fit cerclage wires and reinsert
A3	Displaced or unstable fracture of the proximal femur or greater trochanter	Treat with diaphyseal fitting stem. ORIF greater trochanter as needed (plate or claw)
Type B	**Diaphyseal, not extending into distal diaphysis**	
B1	Cortical perforation: usually results in attempt to remove cement	Bypass with longer stem by two cortical diameters. Consider cerclage wiring distally to prevent propagation
B2	Non-displaced linear crack	Bypass with longer stem by two cortical diameters with cerclage wiring. Consider cortical strut grafts or plating
B3	Displaced fracture of the femur	Expose and reduce the fracture. Fixate with cerclage wiring and cortical strut and bypass with longer stem if possible
Type C	**Distal diaphyseal, extending beyond the longest extent of the longest revision stem, can include distal metaphysic**	
C1	Cortical perforation	Local bone graft with cortical strut graft and cerclage wires as needed
C2	Non-displaced linear crack extending just above knee joint	Cerclage wires and cortical strut graft
C3	Displaced fracture of the distal femur, cannot be bypassed by a femoral stem	ORIF with plate and screw construct

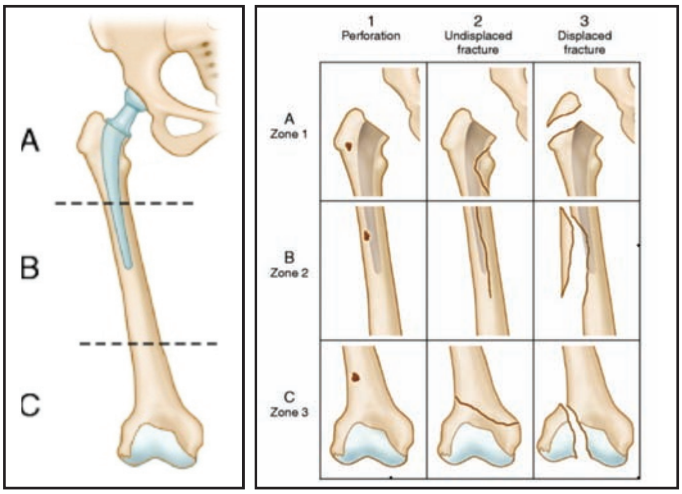


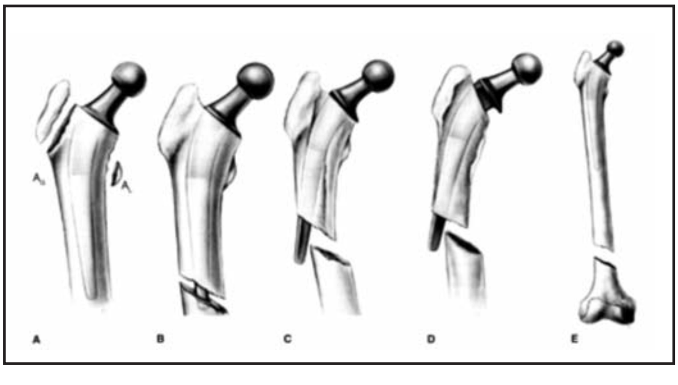
Diagram 1
Adapted with permission from Pike JM, Davidson D, Masri B: Periprosthetic fractures around total hip arthroplasty: Evaluation and management, p 278. In Brown TE, Cui Q, Mihalko WM, Saleh KJ (eds): *Arthritis & Arthroplasty: The Hip.* Saunders Elsievier Philadelphia 2009. (Permission reference pf Case:211469)

Classification *(Table II)*

Table II: Vancouver classification of post-operative periprosthetic fractures of the femur associated with THA as modified by Duncan and Masri *(Diagram 2)*[16]

Type of fracture	Characteristics	Management options
Type A	**Fracture located in the trochanteric region**	
A-G Greater trochanter	Fracture involving greater trochanter	Treat conservatively with protected weight bearing. Indications for ORIF: Displaced > 2.5 cm, abductor weakness due to non-union and chronic pain
A-L Lesser trochanter	Fracture involving smaller trochanter	Treat conservatively with protected weight bearing unless a large portion of the medial cortex is involved
Type B	**Fracture around or just distal to femoral stem**	
B1	Around or just distal to femoral stem, stem well fixed. *See Figure 1.*	Open reduction and internal fixation with cerclage wires alone if long oblique or plate osteosynthesis. This can be achieved with different plates (dynamic compression, locking or Dall-Miles plates).Cortical strut grafts and cerclage fixation can be used separately or utilised in combination with a plate
B2	Around or just distal to femoral stem, stem loose, good bone stock in proximal femur. *See Figure 2.*	The fracture need to be bypassed with a longer (revision) stem with cerclage reinforcement, with or without cortical strut
B3	Around or just distal to femoral stem, stem loose, poor bone stock in proximal femur. *See Figure 3.*	A combination of a revision stem and bone grafting (impaction or strut grafting). In severe osteolysis revision stems with distal screw fixation are preferred. Consider proximal femoral replacement (tumour type prosthesis) for low demand or elderly
Type C	**Fracture is located well below the femoral stem**	Ignore implant and manage fracture first in conventional way (Locking plate, blade plate or condylar screw plate)

Diagram 2. Periprosthetic fractures of hip: A - Type A with lesser or greater trochanter fractures. B - Type B1 fractures: Fractures around or just distal to the tip with stem intact. C - Type B2 fractures: Fractures around or just distal to the tip with the stem loose. D - Type B3 fractures: Fractures around or just distal to the tip with stem loose and poor bone stock in proximal femur. E - Fracture located well below the femoral stem



Adapted with permission from Garbuz DS, Masri BA, Duncan CP: Fractures of the femur following total joint arthroplasty, in Steinberg ME, Garino JP, eds: *Revision Total Hip Arthroplasty.* Philadelphia, PA, Lippincott Williams & Wilkins, 1999, p 497. (Permission reference: Steinberg: 9780781714242)

Figure 1. Vancouver type B1 fracture in an 86-year-old woman (Radiograph A & B). The stem is fixed.

Treatment principles in post-operative femur fractures in hip arthroplasty

1. Both conservative treatment modalities and salvage reconstructive surgery carry significant risk for complications.
2. There is a role for conservative treatment in type A fractures involving either the smaller or greater trochanter.
3. It is not only the fracture position and configuration that dictates choice of treatment, but local and systemic host factors with the baseline (pre-morbid) mental and mobility status should also be considered.
4. The most common periprosthetic fracture in primary hip arthroplasty is type B2 and the most common following revision surgery is type B1.[3]
5. The goals of treatment are a stable, well-aligned prosthesis, preservation or restoration of bone stock with a stable fracture fixation.
6. Successful management requires the combined skills and knowledge of revision surgery as well as fracture dynamics and stabilisation.
7. Type B3 fractures are the most complex fractures to manage and the prevention rationale seems pivotal in this particular group. These fractures are generally as a result of severe osteolysis and if picked up prior to the fracturing event, revision surgery with a dramatic lower morbidity could be offered to the patient. See *Figure 4*.

Special considerations for certain fracture patterns

B1 fractures: Diaphyseal fracture with stable prosthesis

These fractures could generally be managed with plate fixation without bypassing it with a longer stem (as recommended in groups B2 and B3).[18] A few important principles in this group should be kept in mind:

1. Robust fixation methods are required to ensure stability.
2. Minimise soft tissue stripping and use an approach that could facilitate the insertion of a long stem prosthesis if loosening of the device is found intra-operatively.

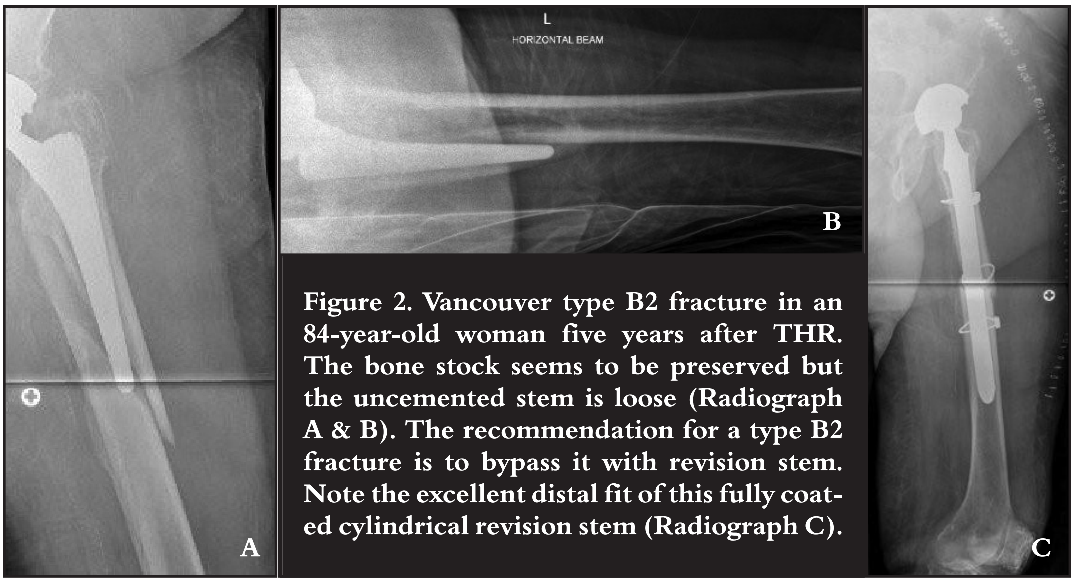


Figure 2. Vancouver type B2 fracture in an 84-year-old woman five years after THR. The bone stock seems to be preserved but the uncemented stem is loose (Radiograph A & B). The recommendation for a type B2 fracture is to bypass it with revision stem. Note the excellent distal fit of this fully coated cylindrical revision stem (Radiograph C).

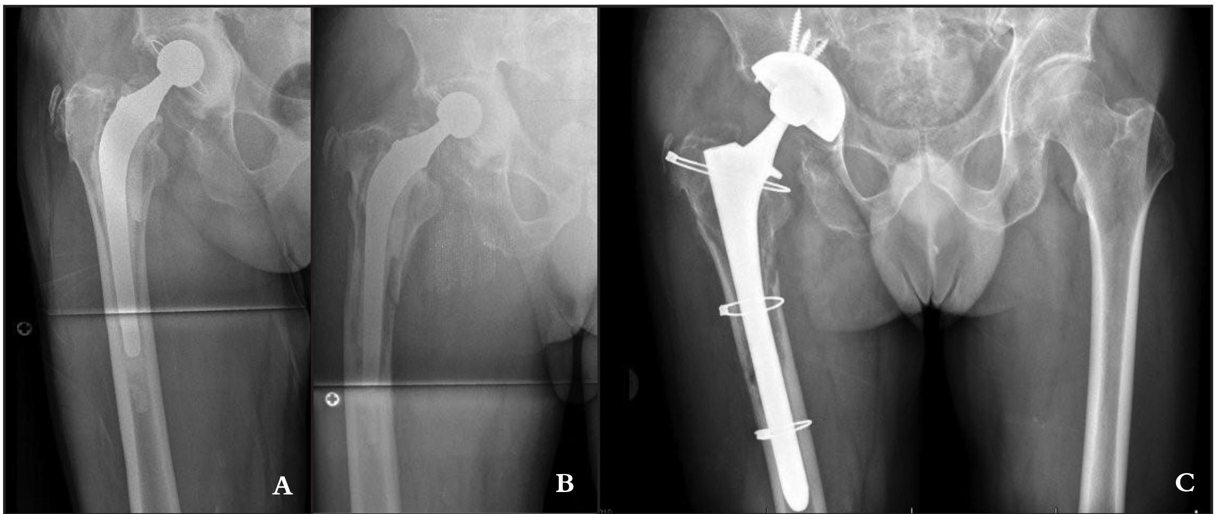


Figure 3. Vancouver type B3 fracture. This 74-year-old woman presents with loosening of the femoral stem and was booked for a revision (Radiograph A). Subsequently she fell and present with a periprosthetic fracture (Radiograph B) in the background of deficient bone stock, most prominent proximally. A revision stem with cables was used to bypass and fixate the fracture (Radiograph C).

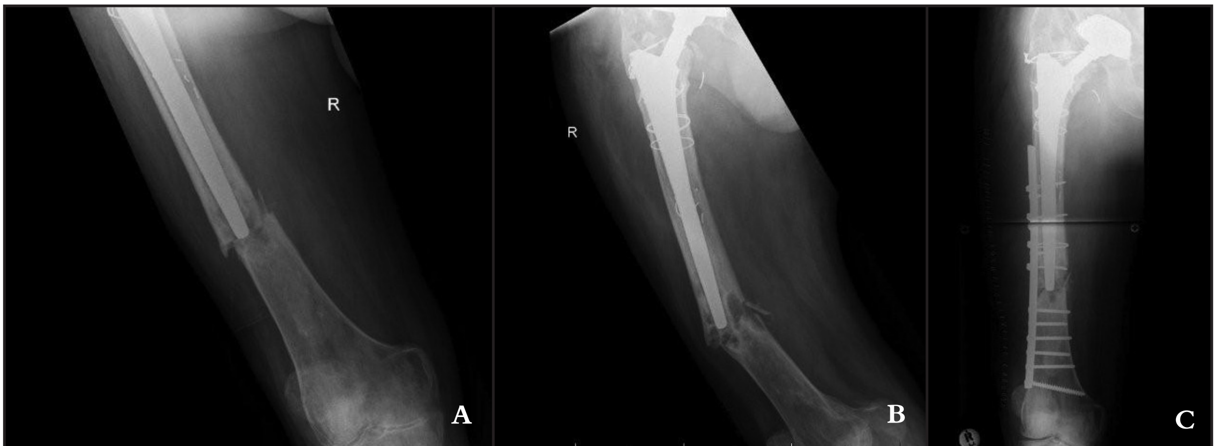


Figure 4. Vancouver type B1 fracture with fracture (Radiograph A & B) around the tip with a well fixated stem. Post-operative radiograph (Radiograph C) showing fracture fixation with non-locking dynamic compression plate augmented by cerclage wires proximally and autogenic bone graft. This is the most common fracture following revision surgery. Of importance is the osteolysis at the tip of the stem that has predisposed this patient to a periprosthetic fracture.

3. A recent review article by Pike *et al*[18] recommended the use of locking or compression plates with indirect fracture reduction methods and minimally invasive techniques where appropriate.
4. Ricci *et al*[19] recommended the minimum invasive technique with a long plate that would bypass the stem with six bicortical screws. See *Figure 4*.

B1 fractures could generally be managed with plate fixation without bypassing it with a longer stem

Greater trochanter fractures

Almost 40 years have passed since Charnley described the trochanteric osteotomy but it seems that the fixation methods for fixing this osteotomy have not prevented the high rate of complications in this procedure. Although this osteotomy is not commonly used anymore, most arthroplasty surgeons will have to deal with a similar scenario in patients presenting with intra-operative or post-operative fractures of the greater trochanter. Osteosynthesis methods are challenging because of the powerful displacement forces of the hip abductors.

In periprosthetic type A-G (greater trochanter) fractures the recommendation is to fix the greater trochanter if the patient is symptomatic or if the displacement exceeds 2.5 cm. The term 'symptomatic' is poorly defined in general, but would generally include well-described symptoms of non-union of the greater trochanter such as limping, thigh pain, bursitis-related pain, weak abductors and dislocations.[20] Fixation of the greater trochanter to the osteotomy of the fracture site is, without any doubt, associated with a fair amount of complications.[20-21]

Osteosynthesis methods are challenging because of the powerful displacement forces of the hip abductors

The original monofilament wiring techniques have non-union rates of up to 38%.[21-23] In 1983 the Dall-Miles cable grip system was introduced with initial promising results.[24] However later studies showed complication rates (cable breakage and non-union the most common) of between 9 and 40%.[23,25] McCarthy *et al*[26] showed a union rate with this system of 91%. Fraying of cables presented a new problem of osteolysis, associated with peri-acetabular loosening.[25,27]

The fourth generation cabling plates utilise a better anatomically shaped plate with a monofilament cable and two multiple filament portions at both ends to prevent kinking during tensioning. Only the monofilament part remains behind after tensioning. Early studies are showing fair results with this new generation fixation method.[22,25]

Periprosthetic fractures of the femur in TKR

Overview and principles

The details of the aetiology and management of periprosthetic fractures of the femur in TKR are beyond the spectrum of this article.

The principles of clinical and radiological evaluation as well as peri-operative workup as described in the previous section for periprosthetic hip fractures in the femur are the same for periprosthetic fractures of the femur in total knee replacement. The Su and associates' classification system[28] for supracondylar periprosthetic femoral fractures is based on the fracture location. A similar classification system to the Su and associates' classification is the one of Lewis and Rorabeck and it is based on fracture displacement and stability of the prosthesis. Management principles are similar irrespective of classification. In principle a loose prosthesis would require a revision prosthesis with a femoral stem,[29] and fractures presenting with a stable prosthesis can be treated with osteosynthesis such as retrograde femur nailing or plating constructs. The most important consideration in periprosthetic fractures around the knee is to keep or restore alignment and rotation and to ensure a stable prosthesis.[5] Revision surgery in periprosthetic fractures complicating TKR carry a very high complication rate with sepsis rates up to 8%, malunion between 5 and 10% and non-union rates up to 15%.[5-8]

Implants used in salvage surgery for periprosthetic fractures

Cortical strut grafts

Cortical strut grafts maintain or reconstruct the cortical support in periprosthetic fractures and reduce the stress load at the weakest points especially in osteoporotic bone with thin cortices.[12] In a study by Haddad *et al*[30] the following technical points regarding the use of strut grafts were made:

1. Use as many cables/wires as needed to provide a stable fixation.
2. The graft should be pre-contoured to ensure maximum bone-graft interface.
3. Blood supply to the femur should be maintained as far as possible and the soft tissue from the linea aspera should not be stripped.
4. Morcellised allograft or autograft should be used at the graft-bone interface.

Cerclage wires or cables

Cerclage cables or wires require a wide soft tissue exposure for application. They can be used alone, in association with a plate (e.g. Dall-Miles plate) or with cortical struts. They resist bending forces but have little resistance against torsional forces in comparison to screws. It is not clear how many should be used to achieve stable fixation.

Although it has limitations, it does a play a very important role not only as a stabiliser, but also in preventing propagation of cortical perforations, cracks and fractures in revision arthroplasty surgery.

Plates

In a study by Dennis *et al*[31] it was shown that a plate fixation (with cabling and bicortical fixation distal) was superior to double cortical strut grafts and cables in Vancouver type B1 fractures. Many plates are described in the literature and will be briefly discussed below.

1. Dynamic compression plates

These plates have been used for many years. The downfall of this plate is that the full length of the plate needs to be exposed surgically and it is inferior in strength to locking plates. The plate exerts a compression force on the fracture depending on the friction force created between plate and bone that is compressed onto bone. Unfortunately this force will be reduced or become redundant if the screw fixation in the bone weakens.

2. Hybrid plate utilising screws and cables

Many different plate designs are available that utilise a hybrid fixation of screws and cabling. It has a high union rate if used with cortical struts. Studies have showed a high failure rate if used alone (without cortical struts) in Vancouver type B1 fractures.[32] The Dall-Miles plate utilises a proximal claw for trochanteric fractures and is widely used.

3. LISS (less invasive surgical system)

These plates have traditionally been popular due to their advantage of a minimally invasive approach. Recently the addition of locking screw holes has contributed to a more rigid fixation that can bridge a segment.

4. Locking plates

These plates provide a rigid fixation but come with a learning curve. The added benefit in revision surgery (theoretically) is the unicortical fixation. Many different designs are available and are especially practical in distal femoral fractures (Vancouver type C). The locking plates can essentially be utilised on the same principles of the traditional LISS plates in selected cases with the benefit of minimal soft tissue stripping and rigid fixation of intra-articular fragments.

Revision stems

1. Wagner conical revision stem

The Wagner stem is a cementless conical-shaped, grit-blasted titanium alloy which obtains its stability from eight longitudinal ridges (fluted). The conical shape ensures excellent transmission of load between bone and the prosthesis and enhances the stress distribution. The ridges ensure rotational stability. Problems with subsidence in the geriatric population have been reported.[33]

2. Locking stem

These stems have distal holes for screw fixation. These stems are preferred especially in the patient with compromised bone stock or severe osteolysis.

3. Fully coated cylindrical stem

The stability of this stem is usually independent of metaphyseal bone. It has an excellent distal fit in the diaphysis. This stem has superb vertical stability but is probably not as stable as the fluted Wagner stem in resisting rotational forces.

Prevention

Prevention is far better than the most advanced method of cure in periprosthetic fractures of the femur. The literature suggest that type B3 fractures (especially) can be prevented by regular follow-up visits,[3] and that this preventative approach is more cost effective than the high costs of the management of these fractures.[17] Common orthopaedic sense should prevail but the following pearls could prevent at least intra-operative fractures:

1. Adequate exposure and soft tissue release should be performed prior to hip dislocation.
2. Adequate reaming should be completed before the templated prosthesis is inserted using the piriformis fossa as the entry point.
3. In revision surgery it is important to split intramedullary cement radially before attempting to remove it.
4. When making cortical windows, great care should be taken to prevent sharp corners that could propagate in fracture lines. These windows should be bypassed by at least two femoral diameters of stem.

Conclusion

There is a constantly growing population undergoing hip and knee replacements and more patients have become candidates for these successful procedures. This has resulted not only in more revision surgery but also in more periprosthetic fractures, which are a rather rare complication in arthroplasty. These fractures carry a complication rate of up to 25% irrespective of conservative or surgical treatment. Successful management of this complication in arthroplasty requires the skills of a good revision surgeon who has the understanding and necessary skills to manage complex fractures. Extra care should be taken by the surgeon who performs arthroplasty surgery to prevent these fractures at all costs. The Vancouver classification scheme is a reliable tool to guide treatment and to prognosticate. Vancouver type B3 fractures (inadequate bone stock) still pose a big challenge for the surgeon and each patient should be individualised for the most appropriate treatment. A loose prosthesis acts as a stress riser at the distal tip and should be revised before this loosening results in a periprosthetic fracture.

The content of this review article is the sole work of the two authors. No benefits of any form have been received from a commercial party related directly or indirectly to the subject of this article.

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