



Treatment Algorithm of Periprosthetic Femoral Fractures

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Nicola Mondanelli, MD, PhD^{1,2,†} , Elisa Troiano, MD^{1,2,†},
Andrea Facchini, MD³, Roberta Ghezzi, MD⁴,
Martina Di Meglio, MD^{1,2}, Nicolò Nuvoli, MD^{1,2},
Giacomo Peri, MD^{1,2}, Pietro Aiuto, MD^{1,2},
Giovanni Battista Colasanti, MD^{2,5}, and Stefano Giannotti, MD^{1,2}

Abstract

Introduction. The ever-expanding indications for total hip arthroplasty are leading to more implants being placed in younger as well as in older patients with high functional demand. Also, prolonged life expectancy is contributing to an overall increment of periprosthetic femoral fractures. The Vancouver classification has been the most used for guiding the surgeon choice since its proposal in 1995. Fractures occurring over a hip femoral implant can be divided into intra-operative and post-operative PFFs, and their treatment depends on factors that may severely affect the outcome: level of fracture, implant stability, quality of bone stock, patients' functional demand, age and comorbidities, and surgeon expertise. There are many different treatment techniques available which include osteosynthesis and revision surgery or a combination of both. The goals of surgical treatment are patients' early mobilization, restoration of anatomical alignment and length with a stable prosthesis and maintenance of bone stock. **Significance.** The aim of this review is to describe the state-of-the-art treatment and outcomes in the management of PFFs. We performed a systematic literature review of studies reporting on the management of PFFs around hip stems and inter-prosthetic fractures identifying 45 manuscripts eligible for the analysis. **Conclusions.** PFFs present peculiar characteristic that must be considered and special features that must be addressed. Their management is complex due to the extreme variability of stem designs, the possibility of having cemented or uncemented stems, the difficulty in identifying the "real" level of the fracture and the actual stability of the stem. As a result, the definition of a standardized treatment is unlikely, thereby high expertise is fundamental for the surgical management of PFFs, so this kind of fractures should be treated only in specialized centres with both high volume of revision joint arthroplasty and trauma surgery.

¹Department of Medicine, Surgery and Neurosciences, University of Siena, Italy

²Section of Orthopedics, Policlinico Santa Maria alle Scotte, Azienda Ospedaliero-Universitaria Senese, Italy

³Arcispedale Santa Maria Nuova, Azienda USL di Reggio Emilia, Italy

⁴Ospedale Santa Maria degli Angeli, Azienda Sanitaria Friuli Occidentale, Italy

⁵Ospedale Santa Maria delle Croci, Azienda USL della Romagna, Italy

[†]Author's note: Elisa Troiano and Nicola Mondanelli contributed equally to the work.

Corresponding Author:

Nicola Mondanelli, Section of Orthopedics, Department of Medicine Surgery and Neurosciences, University of Siena, Siena, Italy; and Azienda Ospedaliero-Universitaria Senese, Viale Mario Bracci 16, 53100 Siena, Italy.

Email: nicola.mondanelli@unisi.it



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Keywords

implant stability, Vancouver classification, bone stock, intra-operative fracture, post-operative fracture, stable stem, loose stem

Introduction

The incidence of periprosthetic femoral fractures (PFFs) has been reported to be between 1% and 11% over a primary and up to 18% over a revised hip femoral stem.¹⁻⁵ The ever-expanding indications for total hip arthroplasty (THA) are leading to more implants being placed in younger as well as in older patients with high functional demand. Prolonged life expectancy, combined with this increase in number of performed arthroplasties, is contributing to an overall increment of PFFs. The Vancouver classification was proposed in 1995 by Duncan and Masri⁶ and since then it has been the most used for guiding the surgeon choice.⁷⁻¹⁰ It has been recently expanded and integrated into the Unified Classification System for Periprosthetic Fractures (UCS-PF).^{11,12} Specific patterns of fracture has also been described for PFFs, with different prevalence over uncemented or cemented stem and apparently over stem design.¹³⁻¹⁸ Also, atypical patterns have been described and periprosthetic atypical femoral fractures (PAFFs) are now accepted to exist.¹⁹⁻²¹ Historically, the treatment of PFFs has been associated with a high rate of complications, poor outcomes and the need for further surgery.²² These fractures can cause frequent and severe comorbidities in elderly patients: multiple studies showed people older than 85 years had poor functional outcomes, greater loss in the ability to perform activities of daily living, and increases of the risk mortality after a PFF.^{23,24}

PFFs occurring over a THA can be divided into intra-operative and post-operative PFFs. Intra-operative fractures are estimated to occur in less than 1% of cemented and in 5.4% of uncemented primary THA, while in revision surgery the incidence of PFFs is higher, up to 3.6% during cemented and 20.9% during uncemented procedures.²⁵

Post-operative PFFs may be associated with stem loosening, with or without concomitant osteolysis,²⁶ and usually they occur with low energy trauma.^{1,27} Their incidence has been estimated to be less than 1% after primary THA and up to 4% following revision THA.^{25,28} Lindahl et al found that the annual incidence of post-operative PFFs varied between .045% and .13% for all THAs recorded in the Swedish National Hip Register between 1979 and 2000,¹ while the cumulative risk of PFFs ranges from .4 to 2.53%.²⁹ These fractures can vary from minor injuries with a minimal effect on patient functionality to catastrophic injuries requiring major reconstruction.³⁰

The treatment of PFFs depends on 5 important factors: level of fracture, stability of the implant and of the

fracture, quality and quantity of bone stock, patient's factors (as age, comorbidities and functional demands), and surgeon experience.^{2,10,22,31-33} The aim of this review is to describe state-of-the-art treatment in the management of PFFs, and to propose a summary to guide treatment choice.

Materials and Methods

A systematic literature review of studies reporting on the management of PFFs around hip stems was performed according to Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines.³⁴ Two researchers independently searched the MEDLINE and Scholar databases to retrieve articles published from inception to April 2021. The language was restricted to English. The terms used were as follows: (periprosthetic femoral fractures) AND (management OR treatment). Reference lists of related papers were also manually searched for potential eligible studies that were included when meeting the inclusion criteria.

Studies that contained relevant information about the management of PFFs after THA or hemiarthroplasty were included. Exclusion criteria were infections, periprosthetic fractures around TKA, and acetabular fractures. Two authors independently screened the titles and abstracts and eliminated duplicates. Both authors reviewed the full texts of the potentially eligible studies and discrepancies were settled by discussion between the 2 authors and the senior authors. Details of the search are highlighted in [Figure 1](#). Our initial search provided 2156 articles and, after applying inclusion and exclusion criteria we identified a total of 49 studies.^{8-10,33,35-79}

INTRA-OPERATIVE Fractures

Classification. Femoral fractures may occur prior or after femoral component insertion and they can be recognised during surgery or immediately afterwards on post-operative radiographs.^{63,80} Several classifications were proposed,^{63,80-82} including a modification of the Vancouver post-operative PFF classification by the same authors.⁶⁷ The focus of the Vancouver classification is pointed on fracture location and configuration, and implant stability. Type A are proximal metaphyseal fractures not involving the diaphysis; type B are proximal diaphyseal fractures not precluding long stem fixation; and type C fractures extend beyond the longest revision stem. Each type is then divided into subtypes: subtype 1 is a simple cortical perforation, subtype 2

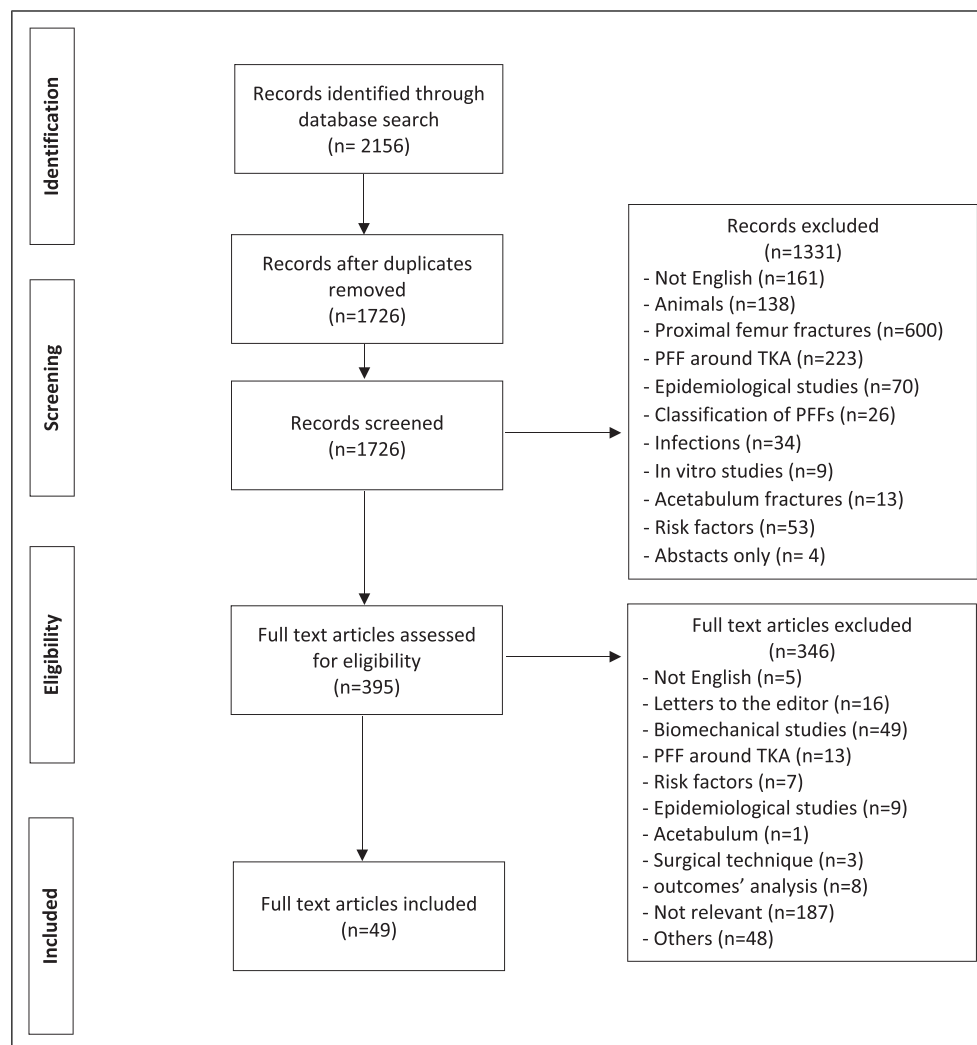


Figure 1. Flow chart representing the search strategy for the articles included in the review according to PRISMA guidelines.

is an undisplaced linear fracture (a so-called crack), and subtype 3 is a displaced and unstable fracture (Table 1 and Figure 2).

Management of Intra-operative PFFs

Intra-operative PFFs are managed depending on localization and pattern of fracture, and stem stability (Table 2). Also, some intra-operative PFFs can be overlooked during surgery or they can be impending fractures of which surgeon becomes aware on post-operative radiographs (“early post-operative PFFs”⁹). In these cases, decision between weight-bearing restriction or immediate revision surgery must be taken.

Vancouver subtype A1 PFFs (proximal metaphyseal cortical perforation). These fractures are frequent especially during revision surgery, and are due to reduced bone

stock from previous surgeries or osteolysis.^{9,35,60} They rarely compromise implant stability and therefore can be treated with locally harvested autograft or can be ignored and observed. No weight-bearing restriction are required.^{9,10,39,60}

Vancouver subtype A2 PFFs (undisplaced linear crack). They occur during femoral broaching or stem insertion, and they usually involve the medial femoral neck and the calcar.⁸³ Cerclage fixation is performed prior to definitive preparation and stem insertion. When an undisplaced linear crack happens at stem insertion, stability of the implant should be assessed intra-operatively: if the stem is stable, cerclage fixation (even a single cable can be enough) may prevent further fracture propagation.^{10,39,60} If the stem is unstable, the fracture is, and must be treated as, a subtype A3 PFF.⁹

Table 1. Vancouver classification of intra-operative PFFs.

Vancouver Classification of Intra-operative PFFs	
A	Proximal Metaphysis
A1	Cortical perforation
A2	Undisplaced linear fracture
A3	Displaced or unstable fractures of the proximal femur or the greater trochanter
B	Diaphyseal fractures not precluding long stem fixation
B1	Cortical perforation
B2	Undisplaced linear fracture
B3	Displaced fracture of the mid-shaft
C	Diaphyseal and distal metaphysis, beyond revision stem
C1	Cortical perforation distal to the stem
C2	Undisplaced linear fracture extending just above the knee
C3	Displaced fracture that cannot be bypassed by a long femoral stem
D*	Dividing 2 implants, a hip and a knee arthroplasty - to be considered as type B or C PFFs according to their pattern

* actually, not included into the Vancouver classification

Vancouver subtype A3 PFFs (displaced or unstable fractures of the proximal femur or the greater trochanter). They are the most frequent intra-operative fractures that need to be addressed, and they can happen both during primary uncemented THA and in revision settings. If these fractures involve the calcar, they usually compromise the tightness of the metaphyseal area, and stem instability or subsidence can happen. Multiple cerclages plus longneck head in case of minor subsidence and adequate stem stability can be enough to offer immediate post-operative weight-bearing. Otherwise, stem fixation must be obtained more distal than the fracture using a longer stem.^{9,10,39,60,63} If a short metaphyseal stem has been prepared for, conversion to a conventional length implant can be sufficient together with cerclages in case of a short fracture line.

Isolated greater trochanteric fragments can be treated by a variety of fixation devices: the use of wires, cables and claw plates have all been advocated (Figure 3(A)).⁶⁰ When an extended trochanteric osteotomy (ETO)^{61,62} is performed to remove a previous implant, a fracture may occur in either the ETO fragment or in the remaining medial part of the femur (Figure 3(B)). As ETO is not usually longer than 13-15 cm, the proximal femur can be wrapped with

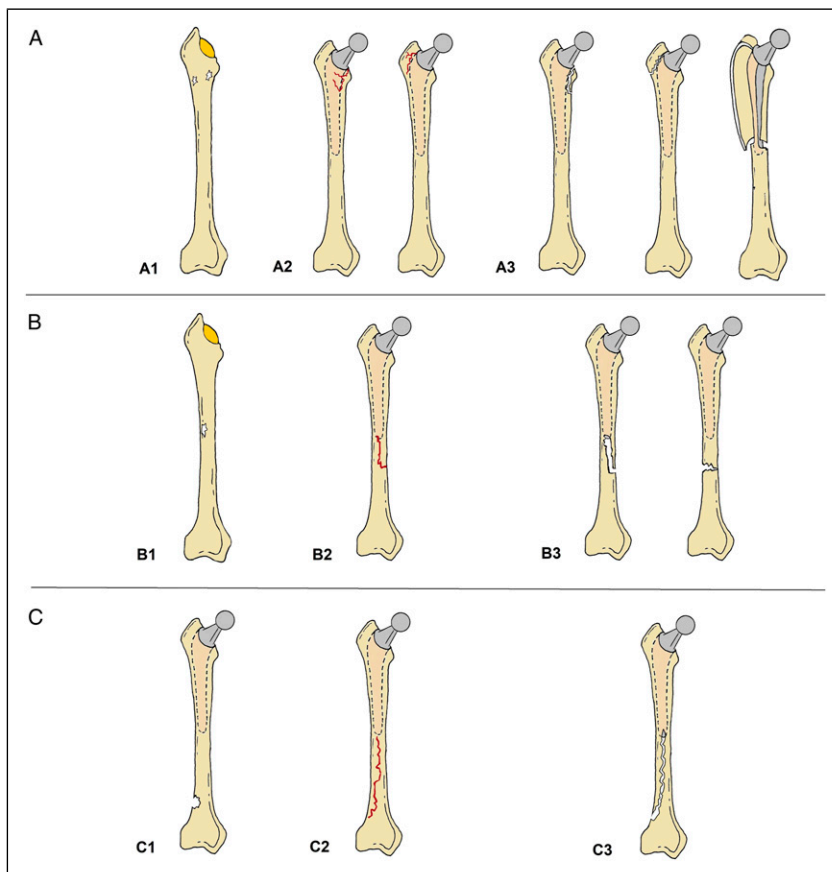
**Figure 2.** Graphical illustration of the Vancouver classification of intra-operative PFFs.

Table 2. Treatment of intra-operative PFFs according to Vancouver type and subtypes.

Treatment of Intra-operative PFFs according to Vancouver Type and Subtypes	
A	Proximal metaphysis
A1	Conservative treatment or autograft, no weight-bearing restriction
A2	Over a stable stem: osteosynthesis (cerclage wire) Over an unstable stem: to be treated as A3
A3	Involving the calcar: Revision to a longer stem Of the greater trochanter: Osteosynthesis (cerclage wire, claw plates) Over an ETO: Osteosynthesis (cerclage wire, claw plates) and/or preventive structural graft
B	Diaphyseal fractures not precluding long stem fixation (required distal grip at least 2x femoral diameter)
B1	Revision to a long stem \pm autograft If longest stem available not long enough: Revision + structural graft and/or plating If recognized post-operatively: Restricted weight-bearing vs stem revision or structural graft or plating
B2	If recognized intra-operatively: Osteosynthesis (cerclage wire) If recognized post-operatively and/or stable configuration: Conservative treatment, restricted weight-bearing If unstable pattern (short oblique or transverse near the tip of the stem): To be treated as B3
B3	Osteosynthesis (cerclage wire, plate) + revision to a long stem \pm structural graft if inadequate bone stock
C	Diaphyseal and distal metaphysis, beyond revision stem
C1	Allograft or autograft, protected weight-bearing
C2	If inherent stability (long spiral): Osteosynthesis with multiple cerclages If unstable fracture and/or deficient bone stock: Osteosynthesis (plate) and/or structural graft
C3	Osteosynthesis (plate) \pm structural graft; overlap the stem if necessary (Very distal fracture: Retrograde nailing)
D	Dividing 2 implants, a hip and a knee arthroplasty Treated as type B or C PFFs according to the fracture pattern

cerclages around an uncemented diaphyseal-fitting stem. Also, if an ETO fragment is at risk of splitting at the greater trochanter base, a structural graft may be employed to prevent fracture.

Vancouver subtype B1 PFFs (diaphyseal cortical perforation). Cortical perforations may be intentional (fenestration for stem removal or coring for screw removal) (Figure 4(A)) or accidental during canal preparation.^{84,85} They should be bypassed with a long stem by at least 2 femoral diameters,⁶⁴ and ideally sealed with autograft. This is more valid in case of lateral/anterior cortex involvement of the subtrochanteric region, as stresses are higher at these levels. If the longest available stem has already been used but protection seems inadequate, a structural graft or a plate should be added. If intra-operatively the pitfall is overlooked, and the perforation at risk of fracture is seen on post-operative radiographs, weight-bearing should be restricted, or revision surgery performed, to avoid predictable consequences (Figure 4(B)).^{9,39,60}

Vancouver subtype B2 PFFs (undisplaced linear crack). These fractures are usually attributed to hoop stresses from broaching or insertion of an uncemented stem.^{63,81,86} If

recognized intra-operatively, cerclage wire to prevent propagation of the fracture line before stem insertion should be performed. A stable fracture configuration recognised after surgery can be treated with observation and protected weight-bearing for up to 12 weeks. Unstable fracture configurations (short oblique or transverse near the tip of the stem) should be treated operatively, as B3 fractures.^{9,39,60}

Vancouver subtype B3 PFFs (displaced fractures of the mid-shaft). These fractures usually occur in revision settings during femoral dislocation^{63,87} or vigorous canal preparation, or in highly osteoporotic patients.^{22,88,89} The fracture must be stabilized before implanting a long stem prosthesis. Double structural grafts placed perpendicular to each other (anterior and lateral cortex) or a combination of structural graft and a plate can be useful to augment bone stock.^{36,50,65} Cortical onlay structural grafts increase cortical strength and have shown good clinical results, and they can also be used prophylactically.⁶⁵ Even if cerclage fixation can appear sufficient to provide fracture stability, a long stem bypassing the fracture by 2 cortical diameters is necessary to achieve axial stability (Figure 5).^{9,35,36,39,50,60,65}

Vancouver subtype C1 PFFs (cortical perforations distal to the stem). Structural allograft or autograft of small defects is



Figure 3. Intra-operative Vancouver subtype A3 PFF. Vancouver subtype A3 intra-operative PFFs can frequently occur during revision surgery and can be stabilized around an uncemented stem with cerclages. **A.** A malunion after a subtrochanteric fracture was treated by THA; an intra-operative fracture occurred and osteosynthesis of the proximal trochanteric fragment with a claw plate and cerclages was performed. **B.** An A3 PFF occurred over an ETO (both the osteotomized fragment and the proximal-medial part of the femur) performed to remove a distally well-fixed stem.

important to avoid leaving a stress concentrator for potential post-operative fracture, and to prevent cement leakage during cementation. If the perforation is large and not well below the stem, a stress riser with higher risk of post-operative fracture exists, therefore the defect should be overlap with structural graft or a plate.^{9,39,60}

Vancouver subtype C2 PFFs (undisplaced linear crack extending just above the knee). Fractures with inherent stability (long spiral) can be treated by multiple cerclages. Unstable fractures or those with deficient bone stock should be treated using structural grafts and/or plates (as described in subtype B3).^{9,39,60}

Vancouver subtype C3 PFFs (displaced fracture of the distal femur that cannot be bypassed by a long femoral stem). These fractures are treated by fixation using locking or standard plates depending on bone quality. If such a fracture propagates to the tip of the stem, the plate should overlap

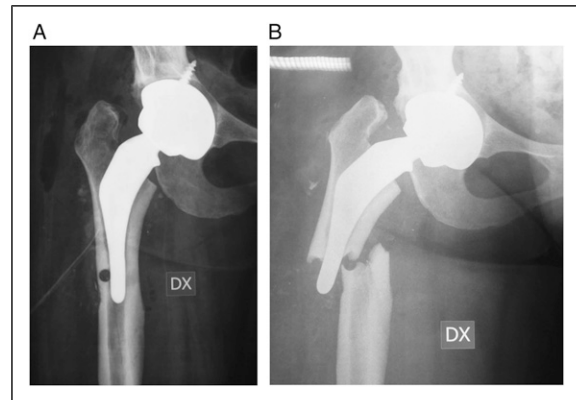


Figure 4. Intra-operative Vancouver subtype B1 PFF. A perforation due to screw removal was not adequately considered intra-operatively nor on post-operative radiographs (**A**), and no action was undertaken. The lateral cortex of the proximal diaphysis is the zone of major tension of the femur, and the perforation is a clear stress concentrator: predictably, a PFFs occurred at the expected point at weight-bearing (**B**).



Figure 5. Intra-operative Vancouver subtype B3 PFF. A B3 PFF occurred during hip dislocation for THA in an osteoporotic patient. The diaphyseal component of the fracture was synthesized with multiple cerclages and an uncemented diaphyseal-fitting modular stem was implanted. After that, suture wires were used to stabilize the greater and the lesser trochanters to the proximal body of the prosthesis.

the stem sufficiently to prevent a stress riser between the 2 implants. If the fracture is distal, and the stem is short, it is theoretically possible to treat this fracture with a retrograde

Table 3. Modified Vancouver classification of post-operative PFFs. Clamshell type was first described as a pseudo-A_L or new-B2, with a loose stem, by Van Houwelingen and Duncan in 2011. Later, Capello et al described it as clamshell type, being the stem stable (A1) or loose (A2). Afterwards, they have been presented as a subtype B2, but they should be properly divided into B1 and B2 PFFs (a proposal: B1_{CS}, B2_{CS}). The same applies to reverse clamshell patterns: stem stability also depends on where the fracture “exits” on both medial and lateral cortices.

Modified Vancouver Classification of Post-operative PFFs

A Proximal metaphysis	
A _G Around the greater trochanter	
A _L Around the lesser trochanter	
B Bed of implant	
B1 Stable stem	
B2 Loose stem, good bone stock	
Burst	Highly comminuted fracture, more frequent in cemented stem
Clamshell*	Displaced fracture of the medial cortex including residual neck, calcar and the lesser trochanter, more frequent in uncemented stem
Reverse clamshell	Displaced fracture of lateral cortex with a “reverse obliquity” pattern
Spiral	More frequent in cemented stem, loose bone-cement and/or cement-stem interface
B3 Loose stem, poor bone stock	
C Clear of the implant, well below the prosthesis	
D Clear of the implant, dividing 2 implants, a hip and a knee arthroplasty	

* this fracture was first described as a pseudo-A_L or new-B2, with a loose stem, by Van Houwelingen and Duncan in 2011; later on, Capello et al described it as clamshell type, being the stem stable (A1) or loose (A2); clamshell (and reverse clamshell, as well) PFFs with a stable stem are included in type B1 PFFs.

intramedullary nail, but it would require a new approach and therefore it seems less feasible than distally extending the already open approach to the femur.^{9,39,60}

Vancouver type D PFFs (dividing a hip and a knee arthroplasty). Type D fractures were not contemplated in the modified Vancouver classification for intra-operative PFFs. They should be treated in accordance with their appearance as type B or C PFFs, with special consideration not to create a stress riser between implants. Therefore, plate fixation (eventually augmented with structural graft) should overlap the stems of the THA and of the total knee arthroplasty (TKA) if stemmed, to distribute gradually the stresses along the entire femur.

POST-OPERATIVE Fractures

Classification. Numerous classifications have been proposed focusing primarily on anatomical location.^{62,80,90-92} Roffman and Mendez⁹³ first introduced the concept of implant stability, while Duncan and Masri⁶ later consolidated the importance of fracture location, implant stability and bone quality,¹² to develop a

valid and effective classification system (the Vancouver classification),⁹⁴ that has been expanded (Table 3 and Figure 6).⁹⁵

Type A fractures are located in the trochanteric region (“apophyseal”) and are subdivided in fractures involving the greater (A_G) or the lesser (A_L) trochanter.

Type B fractures are those around or just distal to the stem (“bed” of the implant), and they are the most common type (up to 80% of all post-operative PFFs). These fractures require surgical management except under exceptional circumstances. Type B PFFs are subdivided in 3 groups: in type B1 fractures, the stem is considered stable and the bone stock adequate; in type B2 fractures, the stem is loose, but satisfactory bone stock is present; in type B3 fractures there is severe bone loss with a loose stem. Furthermore, subtypes of B2 PFFs have been described (burst,⁹⁶ clamshell,¹⁴ reverse clamshell,⁹⁵ spiral).⁹⁷ Also, evidence exists that different B2 subtypes present with different prevalence over uncemented or cemented stem and apparently over stem geometry.¹³⁻¹⁸ Burst fractures, with a highly comminuted pattern, are more frequent in cemented stems.⁹⁶ Clamshell fractures involve the medial cortex including residual neck, calcar and lesser trochanter, the stem can

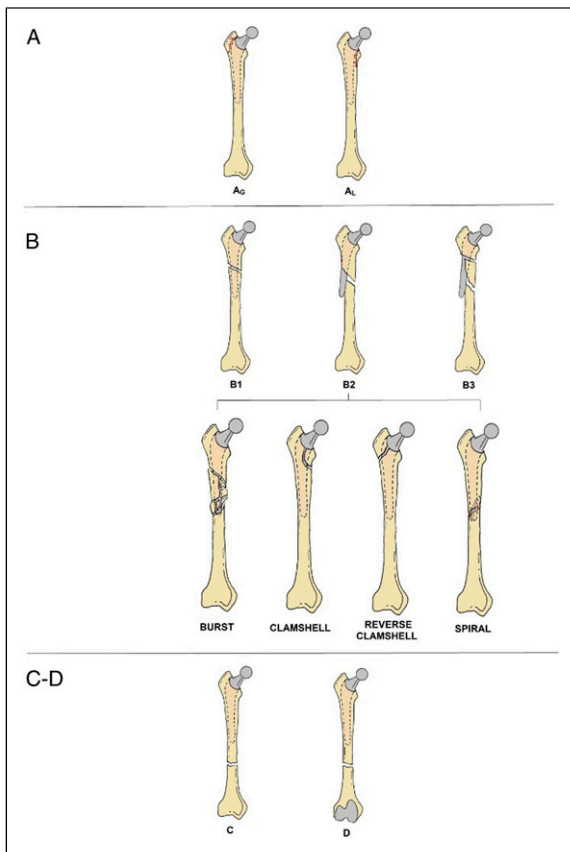


Figure 6. Graphical illustration of the modified Vancouver classification of post-operative PFFs.

be stable or loose, and they are more frequent in anatomical and wedge design uncemented implants.^{13,14} The reverse clamshell pattern presents a displaced fracture of lateral cortex with a “reverse obliquity” pattern, and the stem is frequently loose.⁹⁵ Spiral pattern seems to be more frequent in cemented implants.⁹⁷

Type C fractures are those well below the tip of the stem (“clear” of the implant), while type D PFFs (introduced with the UCS-PF)^{11,12} are those between the tip of the femoral stem of the THA and the femoral component of a TKA (“dividing” the implants). In type D fractures, there are some key points to consider about the knee implant: the location of the fracture with respect to the knee femoral component, the possible loosening of the TKA, and the type of implant (primary or revision). This concept was first introduced by Su et al⁹⁸ and later developed by Fakler et al.⁹⁹

Management of Post-operative PFFs

The goals of surgical treatment are restoration of anatomical alignment and length with a stable prosthesis,

maintenance or enhancement of bone stock, early mobilisation and early union.^{12,35,36,50,71} Intramedullary (revision stems or nails in type C PFFs) or extramedullary (plates, cerclages, structural graft) techniques, or a combination of both, are used to achieve these goals (Table 4). The correct management of the fracture is dictated by the stability of the femoral implant: if the stem remains well-fixed the fracture can be treated with osteosynthesis, otherwise revision of the implant must be considered. A flowchart of the treatment algorithm of post-operative PFFs is represented in Figure 13. Conservative management (protected weight-bearing, traction, casts and braces) was proposed in historical series.^{22,80,91,94,100} Anyway, poor results with revision rates for loosening between 19 and 100% and rates of nonunion/malunion as high as 45% were found.^{22,39,80,101} However, there are cases in which patients are not suitable for surgery from a medical and anaesthesiologic point of view, therefore conservative treatment remains the only possible option.^{8,9,35,36,66,69}

While obtaining the history, care should be taken to note any previous groin or thigh pain to assess for potential issues with the THA prior to the injury, as infection or loosening. If pre-injury radiographs are available, they should be examined and scrutinized as well. First of all, infection must be ruled out, especially whenever loosening is identified.¹⁰² Pre-operative aspiration for cultural growth may require up to 2 weeks for a definitive results, and therefore is not feasible in case of PFFs. Therefore, at surgery aspiration of joint fluid for intra-operative Gram stain and intra-operative alpha-defensin testing, and periprosthetic soft tissues sampling for intra-operative frozen section are recommended.¹⁰² The one-stage revision should be abandoned in favour of a two-stage procedure if suspicion is high and confirmed by intra-operative testing.

Stem stability and adequate bone quality can be difficult to be evaluated from radiographs, therefore pre-operative distinction between type B1 and B2 PFFs is not always possible. Computed tomography (CT) scan can be useful to evaluate bone-stem interface.¹⁰³ Despite careful scrutiny of preoperative images, roughly 20% of stems that were concluded to be stable were found to be loose intraoperatively.^{47,67}

Pre-operative planning is essential. Even if osteosynthesis is scheduled, it is recommended to have a revision implant available in case of possible mobilization found intra-operatively. Also, structural allograft should be available. In fact, they can be used both in fixation and revision settings as they provide fixation with the potential to restore bone stock and increase cortical strength.¹⁰⁴⁻¹⁰⁶ Their aim is to augment both

Table 4. Treatment of post-operative PFFs according to modified Vancouver type and subtypes (see also caption of Table 3).

Treatment of Post-operative PFFs according to Vancouver Type and Subtypes

A Proximal metaphysis		
A _G		
A _{GU}	Undisplaced	Conservative, protected weight-bearing
A _{GD}	Displaced ≥2 cm	Osteosynthesis (cerclage wire, claw plate) ± autograft (if nonunion)
	+ Osteolysis	Osteosynthesis (cerclage wire, claw plate) + impaction bone graft
	+ Metaphyseal osteolysis	Osteosynthesis (cerclage wire, claw plate) + revision to long stem ± bone graft
	A _L	Conservative
B Bed of the implant		
B _I		
B _{I_U}	Undisplaced	Osteosynthesis (MIPO or ORIF) (Vs conservative)
B _{I_D}	Displaced	Osteosynthesis (MIPO or ORIF)
B _{I_{TC}}	Transverse/short oblique, medial comminution, at the tip of a cemented stem	Osteosynthesis + structural graft* vs revision to a long stem + osteosynthesis
B _{I_{CS}}	Clamshell, stable stem	Osteosynthesis ± bone graft
B _{I_{RS}}	Reverse clamshell, stable stem	Osteosynthesis vs revision to long stem
B ₂		
B _{2_B}	Burst	Revision to long stem ± additional rotational stabilization (structural graft and/or plating)
B _{2_{CL}}	Clamshell, loose stem	Revision to long stem ± structural graft
B _{2_{RL}}	Reverse clamshell, loose stem	Revision to long stem + osteosynthesis/strut graft
B _{2_S}	Spiral	Revision to long stem + osteosynthesis
B ₃		Revision to long stem vs APC vs megaprosthesis
C Clear of the implant, well below the prosthesis		Osteosynthesis*; avoid stress-riser between tip of the stem and plate
D Clear of the implant, between a hip and a knee arthroplasty		Treated as type B or C PFFs according to the fracture pattern and knee implant
	Stable TKA with open box	Osteosynthesis with retrograde nailing
	Stable TKA with closed box or stemmed TKA	Osteosynthesis with plate ± structural graft overlapping implants
	Unstable TKA	Revision TKA + preventive extramedullary fixation overlapping implants vs total femur prosthesis

*a treatment algorithm for B_I and C PFFs with potential mechanical and/or biological impairment has been proposed.⁴⁶

mechanically and biologically the construct.¹⁰⁷ In fixation procedures, they are used in conjunction with a plate, both on the medial and/or the anterior aspect of the femur, being the biplanar configuration more stable than the uniplanar 1. In revision settings, they have been used to reinforce the fracture, the calcar on the posteromedial aspect of the proximal femur,^{10,51} or to bypass stress risers (eg the tip of the revision stem touching the anterior cortex).¹⁰⁸ Intra-operative radiographs help to improve the accuracy of fracture reduction, the position of the implant and allow for dynamic screening to check stability of the construct. Post-operative rehabilitation is individualised, and protected weight-bearing may be required up to 12 weeks until radiological healing has occurred.

Vancouver subtype A_G PFFs (fracture of the greater trochanter). These fractures are usually stable. Proximal migration of the fragment of less than 2 cm should be treated conservatively (Figure 7(A)) with protected weight-bearing and avoiding active hip abduction for 6 to 12 weeks. Surgical indications are proximal migration of more than 2.5 cm, instability and weakness in abduction, or nonunion with pain.^{37,38,71} Fixation of the greater trochanter is achieved through the use of cerclage wire or the use of a trochanteric claw plate⁶⁹; autologous graft is recommended in case of nonunion or residual defect (Figure 7(B)).^{38,39}

If the fracture is associated with proximal femoral osteolysis, and the stem is stable, this is usually attributed to polyethylene wear that can be treated with acetabular

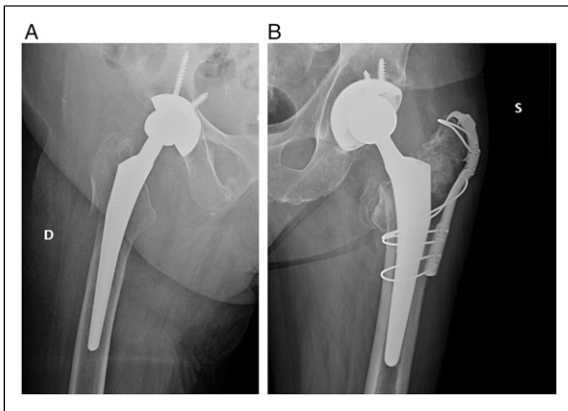


Figure 7. Post-operative Vancouver subtype A_G PFF. A fracture of the greater trochanter (Vancouver A_G) can be treated conservatively if undisplaced (**A**) or surgically if proximal migration of more than 2.5 cm or nonunion is present, eventually with bone grafting (**B**).



Figure 8. Post-operative undisplaced Vancouver subtype B1 PFF. A clamshell type fracture with a stable stem (Vancouver B1, or A1 as proposed by Capello et al) can be treated with stem retention and internal fixation.

revision, impaction grafting and greater trochanter fixation. If the osteolysis extends more distally, the stem can be loose and revision may be advised.^{9,10,35,36,55}

Vancouver subtype A_L PFFs (fracture of the lesser trochanter). These fractures are treated conservatively. A large postero-medial calcar fragment (though unusual) may compromise proximal stem stability, making stem revision necessary with distal diaphyseal fixation.^{9,10,35,36,38,39,55,69} Anyway, a large fragment involves the “bed” of the stem and therefore should be better classified as a type B PFF (with stable or unstable stem).^{13,14}

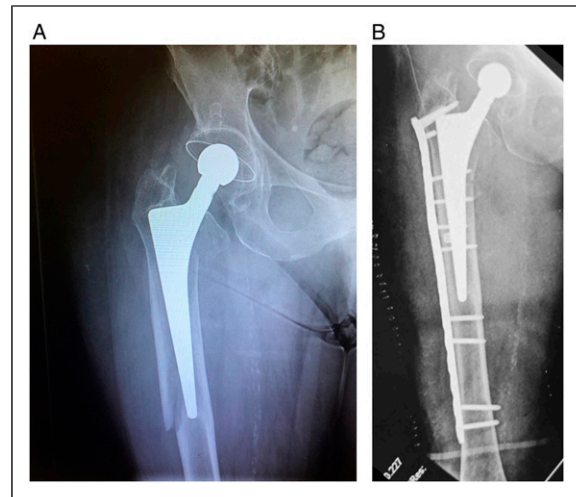


Figure 9. Post-operative displaced Vancouver subtype B1 PFF. A reverse clamshell type fracture (**A**) can be treated with ORIF without revision (**B**) provided that the stem is stable.

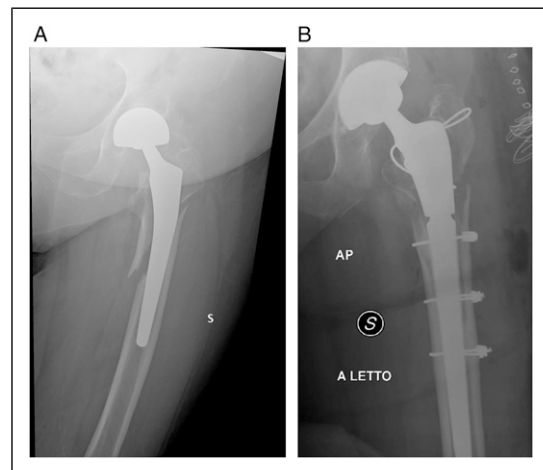


Figure 10. Post-operative Vancouver subtype B2 PFF. **A.** A clamshell type fracture with an unstable stem (Vancouver B2_{CS}, or A2 as proposed by Capello et al). **B.** Post-operative radiographs showing revision to a long stem plus osteosynthesis with multiple cerclages.

Vancouver subtype B1 PFFs (fractures at the level of a stable stem). Undisplaced B1 fractures can be treated conservatively if the fracture presents inherent stability, but operative treatment is nowadays preferred if the patient is surgically fitted (Figure 8).^{66,69} Displaced fractures are operatively treated (Figure 9(A) and Figure 9(B)). In both undisplaced and displaced cases, minimally invasive plate osteosynthesis (MIPO) or open reduction and internal fixation (ORIF) can be advised, depending on fracture’s pattern, the need for anatomical reduction, the need for cerclaging around the stem and for structural

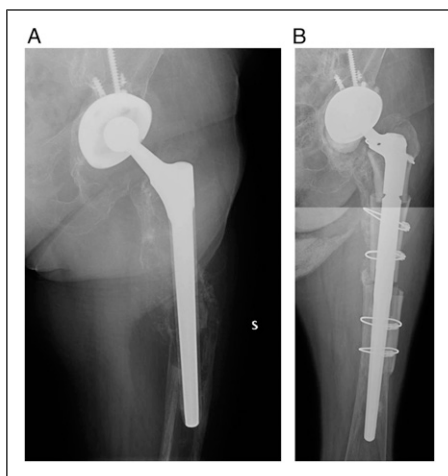


Figure 11. Post-operative Vancouver subtype B3 PFF. A type B3 PFF (A) treated with an APC (B). A double mobility cup was cemented into the well-fixed retained acetabular shell.

graft augmentation, and surgeon's preference and habits.^{9,10,35,36,38-43,47,70}

If the fracture is transverse or short oblique, or presents medial comminution, or is over a cemented stem,⁴⁴ mechanical and biological healing potential are reduced. In these occurrences, revision to a long stem that could be possibly augmented with a structural allograft has also been proposed,^{45,47,72} or a combined surgical and medical approach,^{33,46} to reduce the risk of failure of the fixation construct.

Vancouver subtype B2 PFFs (fracture around an unstable stem, with adequate bone quality). These fractures should be treated by revision with long stem bypassing the most distal fracture line by at least 2 femoral diameters (Figure 10(A) and Figure 10(B)).^{9,35,64} The fractured proximal femur should be always stabilized to the prosthesis and/or to distal femur. Additional rotational stability may be necessary in some cases, using an extramedullary augmentation (plates or structural allografts, or a combination of them).^{38,48,49,52,53} Impaction grafting technique and cemented stem have also been used.^{10,50,51,69}

Vancouver subtype B3 PFFs (fracture with unstable stem and inadequate bone quality). These fractures are difficult to treat due to deficient bone stock (Figure 11(A)). Anyway, these fractures should be treated with long stem revision or an allograft-prosthetic composite (APC)^{38,77} or proximal femoral replacement.^{57,78} A distally locked stem is advised in low demand patient as a salvage procedure.^{38,79} The remnant of the host proximal femur can be wrapped around the new construct (Figure 11(B)).^{36,77,78} Double mobility implants are often used with these constructs to improve

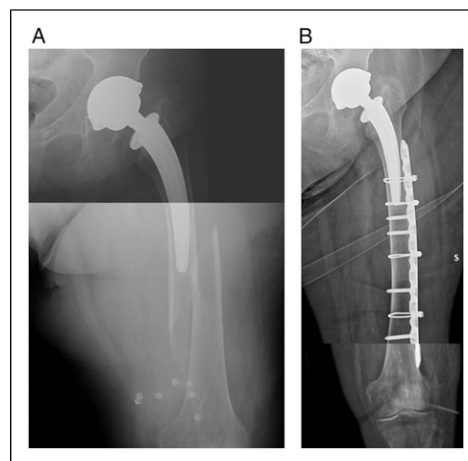


Figure 12. Post-operative Vancouver subtype C PFF. A type C PFF (A) treated with ORIF (B).

joint stability.⁹ Impaction grafting technique and cemented stem have also been used.^{10,50,51,69}

Vancouver type C PFFs (fracture clear of the stem). When the fracture occurs below the tip of the stem (Figure 12(A)), the implant is usually considered stable, but the bone-implant interface should still be carefully examined for any signs of loosening. These fractures can be treated using standard osteosynthesis techniques,^{10,55} singular lateral plate fixation has been the mainstay of treatment for Vancouver C-type PFFs (Figure 12(B)).⁶⁹ When possible, indirect reduction techniques and MIPO should be applied to preserve blood flow to the fracture site by placing the plate in a submuscular, epiperiosteal plane.^{39,47} It is important to avoid a stress riser between the plate and the femoral stem^{9,38}; fractures close to the tip of the stem require therefore a longer plate that span the stem proximally. Ideally, the entire length of the femoral stem should be plated up to the subtrochanteric region. Over the stem, a combination of cables and locking screws seems to guarantee stability of the construct.³⁶

Vancouver type D PFFs (fracture between 2 implants). With regards to Su et al classification, considering a stable femoral component (Su type 1-2), the PFF is treated as a Vancouver type C as previously described.^{36,75,76} In the case of a fracture on a primary TKA with an open box femoral component, a possible surgical option is represented by locked retrograde intramedullary nail.^{36,54,75} A PFF over a stable TKA with a closed box or a stemmed femoral component will require, on the other hand, osteosynthesis with a plate.^{36,74-76} When loosening of the TKA femoral component is observed, due to fracture (Su type 3) or aseptic mobilization, the only possible treatment consists of total revision of the TKA.^{36,75,76} Attention must

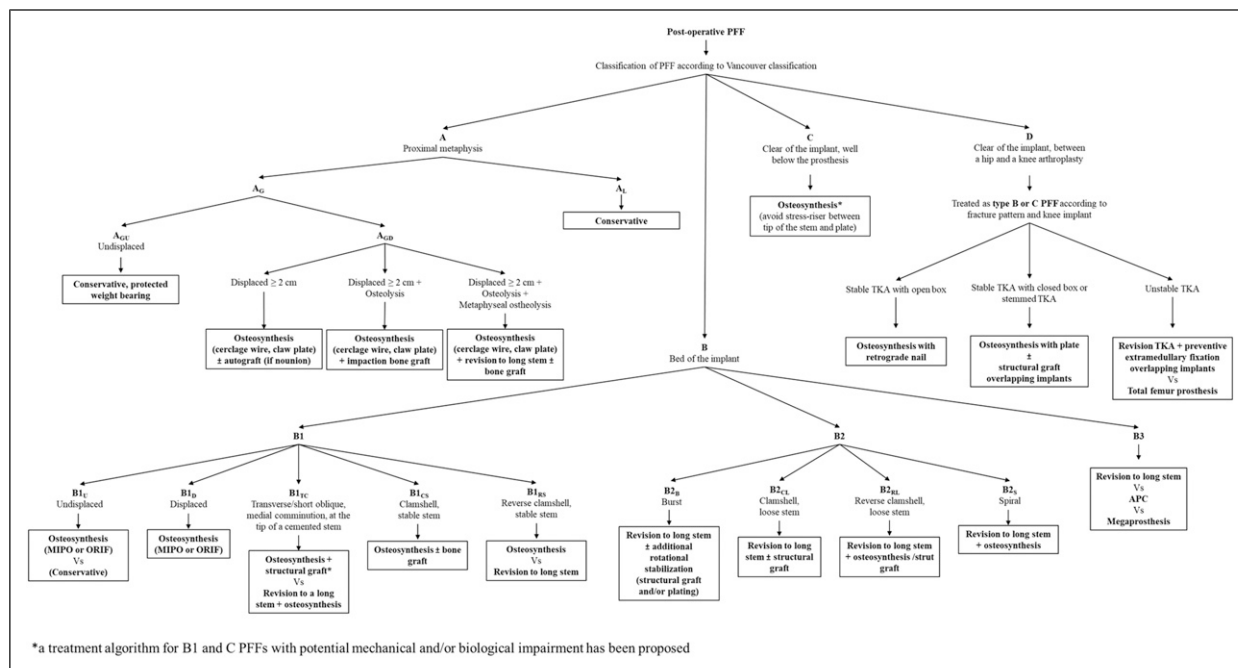


Figure 13. Flowchart of Table 1.

be paid, in all cases, not to leave a segment of weakness between the tips of the hip and knee stems. In order to avoid increased mechanical stresses and a new subsequent interprosthetic fracture, it is recommended to reinforce the construct with additional preventive plating and/or the use of structural graft overlapping the 2 implants.^{58,73} A total femur prosthesis can also be taken into account when both the hip and the knee femoral implants would not have adequate stability.^{38,56,57,59}

Conclusions

Because of the increase in the THAs annually performed, PFFs are going to become more frequent, and their treatment poses a significant challenge to the orthopedic community. The extreme variability of stem designs, the possibility of having cemented or uncemented stems, the difficulty in identifying the “real” level of the fracture and the actual stability of the stem can prevent the definition of a standardized treatment. Both when revision surgery and osteosynthesis are indicated, it must be considered the procedure not as a revision of a stem nor as the fixation of a fracture. PFFs present peculiar characteristic that must be considered and special features that must be addressed. Single plating (even with the biologically preserving MIPO technique) presents limitation especially in B1 PFFs with an unstable fracture configuration or biological impairment. Locking plates are useful in osteoporotic bone

and polyaxial locking plates are useful around a stem. Modular uncemented revision stems (fluted-tapered or fully coated) are easy to use but at least 5 cm of intact diaphysis are required to guarantee stable distal fixation, and synthesis of the proximal fragment is of paramount importance for function (muscle attachment) and bone stock conservation. Structural grafts can add both mechanical and biological support, either in revision or in fixation procedures, and help to restore bone stock for future surgery. Stress concentrators should be avoided, and a plate or a structural graft overlapping the points at risk should be used. If massive bone loss is present, the use of APC or tumor prostheses are justified by evidence in Literature. Cement-in-cement revision can be proposed in selected cases with good and stable cement mantle. Also, impaction grafting with long cemented revision stem for B2 and B3 PFFs has been successfully used.

In conclusion, high expertise is fundamental for the surgical management of PFFs, so this kind of fractures should be treated only in specialized centres with both high volume of revision joint arthroplasty and trauma surgery.

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ORCID iD

Nicola Mondanelli  <https://orcid.org/0000-0002-0684-4197>

References

- Lindahl H, Malchau H, Herberts P, Garellick G. Periprosthetic Femoral Fractures. *J Arthroplasty*. 2005;20(7):857-865. doi:10.1016/j.arth.2005.02.001.
- Capone A, Congia S, Civinini R, Marongiu G. Periprosthetic fractures: epidemiology and current treatment. *Clinical Cases in Mineral and Bone Metabolism*. 2017;14(2):189-196. doi:10.11138/ccmbm/2017.14.1.189.
- Abdel MP, Houdek MT, Watts CD, Lewallen DG, Berry DJ. Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties. *The Bone & Joint Journal*. 2016;98-B(4):468-474. doi:10.1302/0301-620X.98B4.37203.
- Chatziagorou G, Lindahl H, Garellick G, Kärrholm J. Incidence and demographics of 1751 surgically treated periprosthetic femoral fractures around a primary hip prosthesis. *HIP Int*. 2019;29(3):282-288. doi:10.1177/1120700018779558.
- Singh JA, Jensen MR, Lewallen DG. Patient Factors Predict Periprosthetic Fractures After Revision Total Hip Arthroplasty. *J Arthroplasty*. 2012;27(8):1507-1512. doi:10.1016/j.arth.2011.12.010.
- Duncan CP, Masri BA. Fractures of the femur after hip replacement. *Instr Course Lect*. 1995;44:293-304.
- Masri BA, Meek RMD, Duncan CP. Periprosthetic Fractures Evaluation and Treatment. *Clin Orthop Relat Res*. 2004;420:80-95. doi:10.1097/00003086-200403000-00012.
- Giannoudis PV, Kanakaris NK, Tsiridis E. Principles of internal fixation and selection of implants for periprosthetic femoral fractures. *Injury*. 2007;38(6):669-687. doi:10.1016/j.injury.2007.02.050.
- Tsiridis E, Pavlou G, Venkatesh R, Bobak P, Gie G. Periprosthetic femoral fractures around hip arthroplasty: Current concepts in their management. *HIP Int*. 2009;19(2):75-86. doi:10.1177/112070000901900201.
- Abdel MP, Cottino U, Mabry TM. Management of periprosthetic femoral fractures following total hip arthroplasty: a review. *Int Orthop*. 2015;39(10):2005-2010. doi:10.1007/s00264-015-2979-0.
- Duncan CP, Haddad FS. The Unified Classification System (UCS): improving our understanding of periprosthetic fractures. *The Bone & Joint Journal*. 2014;96-B(6):713-716. doi:10.1302/0301-620X.96B6.
- Brady OH, Garbuz DS, Masri BA, Duncan CP. Classification of the hip. *Orthop Clin N Am*. 1999;30(2):215-220. doi:10.1016/S0030-5898(05)70076-6.
- Van Houwelingen AP, Duncan CP. The Pseudo A LT Periprosthetic Fracture: It's Really a B2. *Orthopedics*. 2011;34(9):479-481. doi:10.3928/01477447-20110714-27.
- Capello WN, D'Antonio JA, Naughton M. Periprosthetic fractures around a cementless hydroxyapatite-coated implant: A new fracture pattern is described. *Clin Orthop Relat Res*. 2014;472(2):604-610. doi:10.1007/s11999-013-3137-x.
- Watts CD, Abdel MP, Lewallen DG, Berry DJ, Hanssen AD. Increased Risk of Periprosthetic Femur Fractures Associated With a Unique Cementless Stem Design. *Clin Orthop Relat Res*. 2015;473(6):2045-2053. doi:10.1007/s11999-014-4077-9.
- Chatziagorou G, Lindahl H, Kärrholm J. The design of the cemented stem influences the risk of Vancouver type B fractures, but not of type C: an analysis of 82,837 Lubinus SPII and Exeter Polished stems. *Acta Orthop*. 2019;90(2):135-142. doi:10.1080/17453674.2019.1574387.
- Quah C, Porteous M, Stephen A. Principles of managing Vancouver type B periprosthetic fractures around cemented polished tapered femoral stems. *Eur J Orthop Surg Traumatol*. 2017;27(4):477-482. doi:10.1007/s00590-016-1883-7.
- Fenelon C, Murphy EP, Baig MN, Kearns SR, Murphy CG, Curtin W. Breaking Bad: A Comparative Descriptive Analysis of Periprosthetic Fractures Around Cemented and Uncemented Femoral Stems. *J Arthroplasty*. 2019;34(8):1783-1786. doi:10.1016/j.arth.2019.03.051.
- Bottai V, De Paola G, Celli F, et al. Histological Study of Atraumatic Periprosthetic Fractures: Does Atypical Periprosthetic Fracture Exist?. *Clinical Cases in Mineral and Bone Metabolism*. 2017;14(2):136. doi:10.11138/ccmbm/2017.14.1.136.
- Mondanelli N, Facchini A, Troiano E, Muratori F, Bottai V, Giannotti S. Periprosthetic Atypical Femoral Fractures Exist: A Retrospective Study at a Single Institution. Prevalence on 115 Periprosthetic Femoral Fractures Around a Primary Hip Stem. *J Arthroplasty*. 2021;36(0):2189-2196. doi:10.1016/j.arth.2021.01.066.
- Facchini A, Troiano E, Peri G, Giacché T, Mondanelli N, Giannotti S. Periprosthetic atypical femoral fractures: surgical and pharmacological management. *Geriatr Orthop Surg Rehabil*. 2022;13. submitted.
- Beals RK, Tower SS. Periprosthetic Fractures of the Femur. *Clin Orthop Relat Res*. 1996;327:238-246. doi:10.1097/00003086-199606000-00029.
- Ricci WM, Borrelli J. Operative management of periprosthetic femur fractures in the elderly using biological fracture reduction and fixation techniques. *Injury*. 2007;38(suppl 3):53-58. doi:10.1016/j.injury.2007.08.012.
- Mortazavi SMJ, Kurd MF, Bender B, Post Z, Parvizi J, Purtill JJ. Distal Femoral Arthroplasty for the Treatment of Periprosthetic Fractures After Total Knee Arthroplasty. *J Arthroplasty*. 2010;25(5):775-780. doi:10.1016/j.arth.2009.05.024.
- Parcells B. *Hip and Knee Book*. 2018;30(2):778.

26. Berry DJ. Periprosthetic fractures associated with osteolysis: A problem on the rise. *J Arthroplasty*. 2003;18(3 suppl 1): 107-111. doi:10.1054/arth.2003.50109.
27. Incavo SJ, Beard DM, Puppato 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. Published online.
28. Morrey BF, Kavanagh BF. Complications with revision of the femoral component of total hip arthroplasty. *J Arthroplasty*. 1992;7(1):71-79. doi:10.1016/0883-5403(92)90035-O.
29. Lindahl H. Epidemiology of periprosthetic femur fracture around a total hip arthroplasty. *Injury*. 2007;38(6):651-654. doi:10.1016/j.injury.2007.02.048.
30. Schwarzkopf R, Oni JK. MST hip arthroplasty, And periprosthetic femoral fractures: a review of classification, 68-78. current treatment. *BHJD*. 2013;71(1).
31. Kim Y-H, Mansukhani SA, Kim J-S, Park J-W. Use of Locking Plate and Strut Onlay Allografts for Periprosthetic Fracture Around Well-Fixed Femoral Components. *J Arthroplasty*. 2017; 32(1):166-170. doi:10.1016/j.arth.2016.05.064.
32. Chatziagorou G, Lindahl H, Kärrholm J. Surgical treatment of Vancouver type B periprosthetic femoral fractures. *The Bone & Joint Journal*. 2019;101-B(11):1447-1458. doi:10.1302/0301-620X.101B11.BJJ-2019-0480.R2.
33. Dargan D, Jenkinson MJ, Acton JD. A retrospective review of the Dall-Miles plate for periprosthetic femoral fractures: Twenty-seven cases and a review of the literature. *Injury*. 2014;45(12):1958-1963. doi:10.1016/j.injury.2014.08.034.
34. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*. 2009;339(7716):332-336. doi:10.1136/BMJ.B2535.
35. Tsiridis E, Haddad FS, Gie GA. The management of periprosthetic femoral fractures around hip replacements. *Injury*. 2003;34(2):95-105. doi:10.1016/S0020-1383(02)00257-7.
36. Patsiogiannis N, Kanakaris NK, Giannoudis PV. Periprosthetic hip fractures: an update into their management and clinical outcomes. *EFORT Open Reviews*. 2021;6(1): 75-92. doi:10.1302/2058-5241.6.200050.
37. Pritchett JW. Fracture of the greater trochanter after hip replacement. *Clin Orthop Relat Res*. 2001;390:221-226. doi:10.1097/00003086-200109000-00025.
38. Wu ES, Cherian JJ, Kapadia BH, Banerjee S, Jauregui JJ, Mont MA. Outcomes of post-operative periprosthetic femur fracture around total hip arthroplasty: A review. *Expert Rev Med Dev*. 2014;12(1):61-72. doi:10.1586/17434440.2015.958076.
39. Rayan F, Haddad F. Periprosthetic femoral fractures in total hip arthroplasty - a review. *HIP Int*. 2010;20(4):418-426. doi:10.1177/112070001002000402.
40. Dehghan N, McKee MD, Nauth A, Ristevski B, Schemitsch EH. Surgical Fixation of Vancouver Type B1 Periprosthetic Femur Fractures. *J Orthop Trauma*. 2014;28(12):721-727. doi:10.1097/BOT.000000000000126.
41. Roche-Albero A, Mateo-Agudo J, Martín-Hernández C, Arnaudas-Casanueva M, Gil-Albarova J. Osteosynthesis in Vancouver type B1 periprosthetic fractures. *Injury*. 2021; 52(8):2451-2458. doi:10.1016/j.injury.2021.03.023.
42. Bibiano L, Stamboltsyan G, Touloupakis G, et al. Plate fixation in periprosthetic femur fractures Vancouver type B1: preliminary report of macroscopic evaluation of the cement mantle and short literature review. *Acta Bio-Medica : Atenei Parmensis*. 2019;90(1):31-36. doi:10.23750/ABM.V90I1.6544.
43. Moore RE, Baldwin K, Austin MS, Mehta S. A systematic review of open reduction and internal fixation of periprosthetic femur fractures with or without allograft strut, cerclage, and locked plates. *J Arthroplasty*. 2014;29(5): 872-876. doi:10.1016/j.arth.2012.12.010.
44. Cassidy JT, Kenny P, Keogh P. Failed osteosynthesis of cemented B1 periprosthetic fractures. *Injury*. 2018;49(10): 1927-1930. doi:10.1016/j.injury.2018.07.030.
45. Yassen AT, Haddad FS. The management of type B1 periprosthetic femoral fractures: when to fix and when to revise. *Int Orthop*. 2015;39(9):1873-1879. doi:10.1007/s00264-014-2617-2.
46. Mondanelli N, Troiano E, Facchini A, et al. Combined Surgical and Medical Treatment for Vancouver B1 and C Periprosthetic Femoral Fractures: A Proposal of a Therapeutic Algorithm While Retaining the Original Stable Stem. *Geriatric Orthopaedic Surgery & Rehabilitation*. 2021;12. doi:10.1177/21514593211067072.
47. Corten K, Vanrykel F, Bellemans J, Frederix PR, Simon J-P, Broos PLO. An algorithm for the surgical treatment of periprosthetic fractures of the femur around a well-fixed femoral component. *J Bone Jt Surg Br Vol*. 2009;91-B(11): 1424-1430. doi:10.1302/0301-620X.91B11.22292.
48. Mulay S, Hassan T, Birtwistle S, Power R. Management of types B2 and B3 femoral periprosthetic fractures by a tapered, fluted, and distally fixed stem. *J Arthroplasty*. 2005; 20(6):751-756. doi:10.1016/j.arth.2004.11.020.
49. Wood GCA, Naudie DR, McAuley J, McCalden RW. Locking Compression Plates for the Treatment of Periprosthetic Femoral Fractures Around Well-Fixed Total Hip and Knee Implants. *J Arthroplasty*. 2011;26(6):886-892. doi:10.1016/j.arth.2010.07.002.
50. Tsiridis E, Spence G, Gamie Z, El Masry MA, Giannoudis PV. Grafting for periprosthetic femoral fractures: Strut, impaction or femoral replacement. *Injury*. 2007;38(6): 688-697. doi:10.1016/j.injury.2007.02.046.
51. Tsiridis E, Narvani AA, Haddad FS, Timperley JA, Gie GA. Impaction femoral allografting and cemented revision for periprosthetic femoral fractures. *J Bone Jt Surg Br Vol*. 2004; 86-B(8):1124-1132. doi:10.1302/0301-620X.86B8.14854.
52. Stoffel K, Blauth M, Joeris A, Blumenthal A, Rometsch E. Fracture fixation versus revision arthroplasty in Vancouver type B2 and B3 periprosthetic femoral fractures: a systematic review. *Arch Orthop Trauma Surg*. 2020;140(10): 1381-1394. doi:10.1007/s00402-020-03332-7.

53. Khan T, Grindlay D, Ollivere BJ, Scammell BE, Manktelow ARJ, Pearson RG. A systematic review of Vancouver B2 and B3 periprosthetic femoral fractures. *The Bone & Joint Journal*. 2017;99-B(4 suppl B):17-25. doi:10.1302/0301-620X.99B4.BJJ-2016-1311.R1.
54. Richard RD, Natoli RM, Sorkin AT, Virkus WW, Gaski GE. Retrograde intramedullary nailing below a hip arthroplasty prosthesis: a viable fixation option for periprosthetic and interprosthetic femur fractures. *Int Orthop*. 2020;44(11):2283-2289. doi:10.1007/S00264-020-04734-3.
55. Giaretta S, Momoli A, Porcelli G, Micheloni GM. Diagnosis and management of periprosthetic femoral fractures after hip arthroplasty. *Injury*. 2019;50(suppl 2):S29-S33. doi:10.1016/J.INJURY.2019.01.053.
56. Solarino G, Vicenti G, Moretti L, Abate A, Spinarelli A, Moretti B. Interprosthetic femoral fractures-A challenge of treatment. A systematic review of the literature. *Injury*. 2014;45(2):362-368. doi:10.1016/J.INJURY.2013.09.028.
57. Apprigh SR, Nia A, Schreiner MM, Jesch M, Böhler C, Windhager R. Modular megaprotheses in the treatment of periprosthetic fractures of the femur. *Wien Klin Wochenschr*. 2021;133(11-12):550-559. doi:10.1007/s00508-021-01838-7.
58. Hoffmann MF, Lotzien S, Schildhauer TA. Clinical outcome of interprosthetic femoral fractures treated with polyaxial locking plates. *Injury*. 2016;47(4):934-938. doi:10.1016/j.injury.2015.12.026.
59. Muratori F, Mondanelli N, Prifti X, et al. Total femur prosthesis in oncological and not oncological series. Survival and failures. *J Orthop*. 2020;17:215-220. doi:10.1016/j.jor.2019.11.009.
60. Davidson D, Pike J, Garbuz D, Duncan CP, Masri BA. Intraoperative Periprosthetic Fractures During Total Hip Arthroplasty. *J Bone Jt Surg Am Vol*. 2008;90(9):2000-2012. doi:10.2106/JBJS.H.00331.
61. Chen W-M, McAuley JP, Engh CA, Hopper RH, Engh CA. Extended Slide Trochanteric Osteotomy for Revision Total Hip Arthroplasty*. *J Bone Jt Surg Am Vol*. 2000;82(9):1215-1219. doi:10.2106/00004623-200009000-00001.
62. Younger TI, Bradford MS, Magnus RE, Paprosky WG. Extended proximal femoral osteotomy. *J Arthroplasty*. 1995;10(3):329-338. doi:10.1016/S0883-5403(05)80182-2.
63. Schwartz JT, Mayer JG, Engh CA. Femoral fracture during non-cemented total hip arthroplasty. *J Bone Joint Surg*. 1989;71(8):1135-1142. doi:10.2106/00004623-198971080-00003.
64. Larson JE, Chao EYS, Fitzgerald RH. Bypassing femoral cortical defects with cemented intramedullary stems. *J Orthop Res*. 1991;9(3):414-421. doi:10.1002/jor.1100090314.
65. Haddad FS, Duncan CP. Cortical onlay allograft struts in the treatment of periprosthetic femoral fractures. *Instr Course Lect*. 2003;52:291-300. Published online.
66. Lee Y-K, Kim JT, Kim K-C, Ha Y-C, Koo K-H. Conservative Treatment for Minimally Displaced Type B Periprosthetic Femoral Fractures. *J Arthroplasty*. 2017;32(11):3529-3532. doi:10.1016/J.ARTH.2017.05.057.
67. Laurer HL, Wutzler S, Possner S, et al. Outcome after operative treatment of Vancouver type B1 and C periprosthetic femoral fractures: Open reduction and internal fixation versus revision arthroplasty. *Arch Orthop Trauma Surg*. 2011;131(7):983-989. doi:10.1007/s00402-011-1272-y.
68. 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. <https://pubmed.ncbi.nlm.nih.gov/24032586/>. Accessed January 11, 2022.
69. Marsland D, Mears SC. A Review of Periprosthetic Femoral Fractures Associated With Total Hip Arthroplasty. *Geriatric Orthopaedic Surgery & Rehabilitation*. 2012;3(3):107-120. doi:10.1177/2151458512462870.
70. Fleischman AN, Chen AF. Periprosthetic fractures around the femoral stem: Overcoming challenges and avoiding pitfalls. *Ann Transl Med*. 2015;3(16):234. doi:10.3978/j.issn.2305-5839.2015.09.32.
71. Brand S, Ettinger M, Omar M, Hawi N, Krettek C, Petri M. Concepts and Potential Future Developments for Treatment of Periprosthetic Proximal Femoral Fractures. *Open Orthop J*. 2015;9(1):405-411. doi:10.2174/1874325001509010405.
72. Zheng H, Gu H, Shao H, et al. Treatment and outcomes of Vancouver type B periprosthetic femoral fractures. *The Bone & Joint Journal*. 2020;102-B(3):293-300. doi:10.1302/0301-620X.102B3.BJJ-2019-0935.R1.
73. Scolaro JA, Schwarzkopf R. Management of interprosthetic femur fractures. *J Am Acad Orthop Surg*. 2017;25(4):e63-e69. doi:10.5435/JAAOS-D-15-00664.
74. Borade A, Sanchez D, Kempegowda H, et al. Minimally Invasive Plate Osteosynthesis for Periprosthetic and Interprosthetic Fractures Associated with Knee Arthroplasty: Surgical Technique and Review of Current Literature. *J Knee Surg*. 2019;32(5):392-402. doi:10.1055/s-0039-1683443.
75. Romeo NM, Firoozabadi R. Interprosthetic Fractures of the Femur. *Orthopedics*. 2018;41(1):e1-e7. doi:10.3928/01477447-20170727-01.
76. Pires RES, de Toledo Lourenço PRB, Labronici PJ, et al. Interprosthetic femoral fractures: proposed new classification system and treatment algorithm. *Injury*. 2014;45(suppl 5S5):S2-S6. doi:10.1016/S0020-1383(14)70012-9.
77. 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*. 2006;88(5):953-958. doi:10.2106/JBJS.E.00120.
78. Klein GR, Parvizi J, Rapuri V, et al. Proximal femoral replacement for the treatment of periprosthetic fractures. *J Bone Joint Surg*. 2005;87(8):1777-1781. doi:10.2106/JBJS.D.02420.
79. Sexton SA, Stossel CA, Haddad FS. The Kent hip prosthesis. *J Bone Jt Surg Br Vol*. 2006;88-B(3):310-314. doi:10.1302/0301-620X.88B3.17087.
80. Johansson JE, McBroom R, Barrington TW, Hunter GA. Fracture of the ipsilateral femur in patients with total hip

- replacement. *J Bone Joint Surg*. 1981;63(9):1435-1442. doi: [10.2106/00004623-198163090-00009](https://doi.org/10.2106/00004623-198163090-00009).
81. Stuchin SA. Femoral shaft fracture in porous and press-fit total hip arthroplasty. *Orthop Rev*. 1990;19(2):153-159.
 82. Mallory TH, Kraus TJ, Vaughn BK. Intraoperative femoral fractures associated with cementless total hip arthroplasty. *Orthopedics*. 1989;12(2):231-239. doi: [10.3928/0147-7447-19890201-06](https://doi.org/10.3928/0147-7447-19890201-06).
 83. Miettinen SSA, Mäkinen TJ, Kostensalo I, et al. Risk factors for intraoperative calcar fracture in cementless total hip arthroplasty. *Acta Orthop*. 2016;87(2):113-119. doi: [10.3109/17453674.2015.1112712](https://doi.org/10.3109/17453674.2015.1112712).
 84. Talab YA, States JD, Everts CM. Femoral Shaft Perforation. *Clin Orthop Relat Res*. 1979;:158-165.
 85. Wade FA, Parvizi J, Sharkey PF, Purtill JJ, Hozack WJ. Femoral Perforation Complicating Contemporary Uncemented Hip Arthroplasty. *J Arthroplasty*. 2006;21(3):452-455. doi: [10.1016/j.arth.2005.06.016](https://doi.org/10.1016/j.arth.2005.06.016).
 86. Fitzgerald RH, Brindley GW, Kavanagh BF. The Uncemented Total Hip Arthroplasty. *Clin Orthop Relat Res*. 1988;235:61-66. doi: [10.1097/00003086-198810000-00007](https://doi.org/10.1097/00003086-198810000-00007).
 87. Kavanagh BF. Femoral fractures associated with total hip arthroplasty. *Orthop Clin N Am*. 1992;23(2):249-257.
 88. Wu CC, Au MK, Wu SS, Lin LC. Risk factors for post-operative femoral fracture in cementless hip arthroplasty. *Journal of the Formosan Medical Association = Taiwan yi zhi*. 1999;98(3):190-194.
 89. Lindahl H, Malchau H, Odén A, Garellick G. Risk factors for failure after treatment of a periprosthetic fracture of the femur. *J Bone Jt Surg Br Vol*. 2006;88-B(1):26-30. doi: [10.1302/0301-620X.88B1.17029](https://doi.org/10.1302/0301-620X.88B1.17029).
 90. Graham SM, Moazen M, Leonidou A, Tsiridis E. Locking plate fixation for Vancouver B1 periprosthetic femoral fractures: A critical analysis of 135 cases. *J Orthop Sci*. 2013;18(3):426-436. doi: [10.1007/s00776-013-0359-4](https://doi.org/10.1007/s00776-013-0359-4).
 91. Mont MA, Maar DC. Fractures of the ipsilateral femur after hip arthroplasty. *J Arthroplasty*. 1994;9(5):511-519. doi: [10.1016/0883-5403\(94\)90098-1](https://doi.org/10.1016/0883-5403(94)90098-1).
 92. Bethea JS, DeAndrade JR, Fleming LL, Lindenbaum SD, Welch RB. Proximal femoral fractures following total hip arthroplasty. *Clin Orthop Relat Res*. 1982;170:95-106. doi: [10.1097/00003086-198210000-00013](https://doi.org/10.1097/00003086-198210000-00013).
 93. Roffman M, Mendes DG. Fracture of the femur after total hip arthroplasty. *Orthopedics*. 1989;12(8):1067-1070. doi: [10.3928/0147-7447-19890801-06](https://doi.org/10.3928/0147-7447-19890801-06).
 94. Brady OH, Garbuz DS, Masri BA, Duncan CP. The reliability of validity of the Vancouver classification of femoral fractures after hip replacement. *J Arthroplasty*. 2000;15(1):59-62. doi: [10.1016/S0883-5403\(00\)91181-1](https://doi.org/10.1016/S0883-5403(00)91181-1).
 95. Karam J, Campbell P, Desai S, Hunter M. Periprosthetic proximal femoral fractures in cemented and uncemented stems according to Vancouver classification: observation of a new fracture pattern. *J Orthop Surg Res*. 2020;15(1):100. doi: [10.1186/s13018-020-01619-4](https://doi.org/10.1186/s13018-020-01619-4).
 96. Phillips JRA, Boulton C, Moran CG, Manktelow ARJ. Periprosthetic fractures around Exeter stems: a new injury?. *Orthop Proc*. 2012;94:187.
 97. Grammatopoulos G, Pandit H, Kambouroglou G, et al. A unique peri-prosthetic fracture pattern in well fixed femoral stems with polished, tapered, collarless design of total hip replacement. *Injury*. 2011;42(11):1271-1276. doi: [10.1016/j.injury.2011.01.008](https://doi.org/10.1016/j.injury.2011.01.008).
 98. Su ET, DeWal H, Di Cesare PE. Periprosthetic femoral fractures above total knee replacements. *J Am Acad Orthop Surg*. 2004;12(1):12-20. doi: [10.5435/00124635-200401000-00003](https://doi.org/10.5435/00124635-200401000-00003).
 99. Fakler JKM, Pönick C, Edel M, et al. A new classification of TKA periprosthetic femur fractures considering the implant type. *BMC Musculoskel Disord*. 2017;18(1):1-8. doi: [10.1186/s12891-017-1855-z](https://doi.org/10.1186/s12891-017-1855-z).
 100. Scott R, Turner R, Leitzes S, Aufranc O. Femoral fractures in conjunction with total hip replacement. *J Bone Joint Surg*. 1975;57(4):494-501. doi: [10.2106/00004623-197557040-00009](https://doi.org/10.2106/00004623-197557040-00009).
 101. Jensen TT, Overgaard S, Mossing NB. Partridge cerclene system for femoral fractures in osteoporotic bones with ipsilateral hemi/total arthroplasty. *J Arthroplasty*. 1990;5(2):123-126. doi: [10.1016/S0883-5403\(06\)80230-5](https://doi.org/10.1016/S0883-5403(06)80230-5).
 102. Abdel Karim M, Andrawis J, Bengoa F, et al. Hip and Knee Section, Diagnosis, Algorithm: Proceedings of International Consensus on Orthopedic Infections. *J Arthroplasty*. 2019;34(2S):S339-S350. doi: [10.1016/j.arth.2018.09.018](https://doi.org/10.1016/j.arth.2018.09.018).
 103. Blum A, Gondim-Teixeira P, Gabiache E, et al. Developments in imaging methods used in hip arthroplasty: A diagnostic algorithm. *Diagnostic and Interventional Imaging*. 2016;97(7-8):735-747. doi: [10.1016/j.diii.2016.07.001](https://doi.org/10.1016/j.diii.2016.07.001).
 104. Head WC, Malinin TI. Results of onlay allografts. *Clin Orthop Relat Res*. 2000;371:108-112. doi: [10.1097/00003086-200002000-00012](https://doi.org/10.1097/00003086-200002000-00012).
 105. Head WC, Malinin TI, Emerson RH, Mallory TH. Restoration of bone stock in revision surgery of the femur. *Int Orthop*. 2000;24(1):9-14. doi: [10.1007/s002640050003](https://doi.org/10.1007/s002640050003).
 106. Head WC, Emerson RH, Malinin TI. Structural bone grafting for femoral reconstruction. *Clin Orthop Relat Res*. 1999;369:223-229. doi: [10.1097/00003086-199912000-00023](https://doi.org/10.1097/00003086-199912000-00023).
 107. Khashan M, Amar E, Drexler M, Chechik O, Cohen Z, Steinberg EL. Superior outcome of strut allograft-augmented plate fixation for the treatment of periprosthetic fractures around a stable femoral stem. *Injury*. 2013;44(11):1556-1560. doi: [10.1016/j.injury.2013.04.025](https://doi.org/10.1016/j.injury.2013.04.025).
 108. Tower SS, Beals RK. Fractures of the femur after hip replacement: The Oregon experience. *Orthop Clin N Am*. 1999;30(2):235-247. Published online. [10.1016/S0030-5898\(05\)70078-X](https://doi.org/10.1016/S0030-5898(05)70078-X).