Periprosthetic fractures: epidemiology and current treatment

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Summary

Periprosthetic fractures are becoming increasingly frequent due to aging population and growing number of total joint replacements involving joints different from hip and knee, such as shoulder and elbow. The treatment of these fractures still represents one of the major challenges for the orthopedic surgeon. Despite all efforts to understand and treat these patients, high rate of failure and mortality are still reported. In this review, the epidemiology of periprosthetic fractures, risk factors and results of surgical treatment are disclosed. Moreover, we propose a treatment algorithm based on the findings of the New Unified Classification System.

KEY WORDS: periprosthetic fractures; UCS classification; revision surgery; anabolic drugs/bone healing.

Background

Periprosthetic fractures (PF) are considered fractures associated with an orthopedic implant, whether a replacement or internal fixation device. The global incidence of all types of PF is increasing constantly due to the growing number of primary joint arthroplasties and revision surgeries (1). Moreover, patients who demand for arthroplasty are becoming older and more active due to the healthcare improvements.

The total amount of PF is mainly determined by fractures about hip and knee due to their marked predominance of procedures compared to the other joints. However, the growth rates of shoulder arthroplasties are becoming even higher than the rates of hip and knee procedures (2).

We therefore focused our review on fractures around hip, knee and shoulder arthroplasty.

Epidemiology

Several studies in the literature have suggested rates of postoperative PF after primary total hip arthroplasty (THA) ranging from 0.1 to 18%, after total knee arthroplasty (TKA) from 0.3 and 5.5% and after total shoulder arthroplasty (TSA) from 0.5 to 3% (3).

Intraoperative fractures may be occult, in particular in acetabulum after THA (4) and in supracondylar femur after TKA (3). The rate of femoral intra-operative fractures is around 1.7% for primary THA compared to 20-year postoperative fracture probability of 3.5% (5). Periprosthetic knee fractures performing TKA are rare and the reported incidence, ranging from 0.3% to 3.13%, may be under-estimated (6). In TSA the reported rate of intra-operative humeral fracture is 1.2% and it represents the major complication during humeral stem fixation (3, 5).

Due to the increasing number of arthroplasties performed in the last thirty years, the number of revision surgery is growing constantly, particularly in elderly patients. PF are significantly more common after revision surgery and may be associated with poor bone quality, stress shielding, osteolysis and consequent bone loss. The incidence of PF after revision THAs ranges from 4 to 11%, and even up to 30% incidence is reported after knee revision surgery (3).

PF will have a deep impact in community health care resources because are associated with higher rates of morbidity and mortality. Toogood et al. reported results of a nation-wide survey and they found that patients admitted to hospital for revision surgery after PF ranged from 4.2 to 7.4% (7). The diagnosis disproportionately impacts women and an older population, when compared to the other reasons for revision (mechanical complication, infection, osteolysis, articular bearing surface wear, dislocation). Specifically, the mean age for the PF patients was 74.6 years and 9.6 years older than all other revisions as a combined group. More often these patients have been admitted emergently or urgently; they had longer hospitalization mean time and higher mortality (7).

Drew et al. reviewed 291 patients treated for periprosthetic femur fractures. They found out a mortality of 13.1% and of 15.8 % after 12 and 18 months, respectively. Furthermore, patients have a chance of either death or reoperation at one year of 24% (8). Bhattacharyya et al. compared one-year mortality in three groups of different surgical treatments: hip fracture (16%), periprosthetic femoral fractures (11%), primary THA and TKA (2.9%) (9).

A retrospective review carried out by Zheng et al. showed that even when appropriate surgical treatment is achieved, patients with periprosthetic hip fracture could never obtain a complete recovery and clinical outcomes are significantly worse (10).

Causes and risk factors

As outlined above PF disproportionately impacts women and elderly population (7).
Most frequently, periprosthetic fracture is the result of low-energy trauma, which has been shown to account for 75% of fractures, in one report (11).
Significant comorbidities, osteoporosis/osteopenia, rheumatoid arthritis (RA) and revision surgery are all contributing factors (3). Osteopenia was described as a crucial risk factor for 75% of cases (12) in humeral PFs. Other studies showed that almost 50% of patient with humeral PF had a diagnosis of RA (3). Platzer et al. (13) reported the presence of severe osteoporosis or RA in 73% of patients treated for distal femoral PF.
The evalutation of implants fixation and the prevention of loosening are essential in order to reduce the risk of PFs. Lindahl et al. suggest that routine radiographic follow-up in patients with primary or revision THA is mandatory: in fact, they found out that 51-66% patients had a loose stem at the time of fracture (11).
In several studies some intra-operative fractures deserved special mention due to the difference in mechanism of injury, risk factors and treatment. In total shoulder arthroplasty risk factors involved are female sex, ASA (Classification 3 or 4) and diagnosis of post-traumatic arthritis (14). In revision hip arthroplasty, intra-operative femur fracture has an incidence of 12% despite 1.7% of primary THA; risk factors are: female sex, age over 65, cementless stems (5, 15). They are often associated with bone and soft tissue deformities as reported in case of THA for development dysplasia of the hip (DDH) (16).
Surgeon experience and a proper surgical technique can influence the incidence of PF. In primary and revision THA under-reaming of the acetabulum and a forceful femoral preparation for stem insertion are commonly considered risk factors for fractures. In shoulder arthroplasty excessive external rotation of the humerus during the procedure must be avoided (3). Major mistakes as femoral anterior notching in total knee replacement have been proven to be associated in 10-46% of cases with supracondylar fractures (17) even though some recent studies disproved that (3).
Several studies reported higher rates of fractures after cementless implants and press-fit techniques (4, 5, 18-20). A review carried out by Abdel et al. point out that the femoral intra-operative fractures occur 14 times more often when a cementless stem is used for THA. Furthermore, post-operative fractures are 3 times more frequent with cementless stems (5). Monoblock cups (18), elliptical cups (4) and extreme proximal taper angle stems (20) have been shown to be risk factors for PF. In TKA, the implant design influences the type of resection from the intercondylar notch. So, the relative risk for distal femoral fracture is 4.74 when comparing a posterior-stabilized implant with a cruciate-retaining implant (21). In TSA, no definitive conclusions could be reached about the impact of implant design, technique for preparation of the humerus and glenoid, and cemented *vs* cementless implantation on PF incidence.

Classification, management and results

The principles of management of PF are basically founded on the location of the fracture, the stability of the implant and the amount of bone loss. Over the years PF affecting every single anatomic joint have been evaluated by dozens of different classifications (22-25) which represented a slight adjustment of the previous and might become redundant.
Of all the proposed classification systems for periprosthetic fractures, the Vancouver Classification is the most widely applied. It became widely accepted due to the significant intra- and inter-observer reliability, and therefore because offers an accurate tool for guiding therapeutic plans (26). The Vancouver classification divides periprosthetic femoral fractures into types A, B, and C and further categorizes type A into two subtypes (A_G and A_L) and type B fractures into three subtypes (B1, B2, and B3).
Duncan et al. in 2014 *“incorporated what has been learnt over the years into a New Unified Classification System (UCS) covering the management of all periprosthetic fractures”* (27). They expand Vancouver Classification, include three specific fractures types (D, E and F) and combined it with AO/OTA fracture and dislocation Classification achieving an unique classification system (Table 1).
The UCS has been tested in pelvic and femur fractures proving a significant and substantial inter- and intra-observer agreement (28), further studies are required to confirm it and to test UCS in other joints.
The decision making and results of PF treatment (Tables 1, 2, 3, 4) depends on fracture pattern, location and it is strictly linked to characteristics of patients (age, daily activities, expectations, comorbidities, quality of bone).
According to UCS classification (27), **Type A** are fractures of an aphophysis/protuberance of bone. According to the functional role of soft tissues attached, treatment choice changes: even if lesser trochanter of the femur and displaced coracoids process of the scapula are treated conservatively, the greater tuberosity of the humerus, the superior pole of patella, the tibial tuberosity and greater trochanter instead require early operation.
Type B fracture is located in the bed supporting or adjacent to an implant and the sub-classification is equivalent to Vancouver classification.
Type B1 are fractures involving well fixed implants. The treatment depends on fracture patterns and it is closely related to the bone segment involved; the management includes reduction and fixation using plates with cerclage and screws (29-33). Several implants with different locking systems have been proposed in order to improve the fixation of the fracture around or close to the stem: e.g. Dall-Miles plates, Hook plates, Cable-ready system, Locking compression plates (LCP), Variable angle locking plate (VA-LCP), Locking attachment plates (LAP). Stoeffel et al. in a systematic review of 1571 case of femoral PFs (70.4% Vancouver type B1) found that close reduction and minimally invasive plate osteosynthesis (MIPO) using locking compression plates (LCP) had lower rates of nonunion and refracture than open reduction and conventional plates (nonunion: 0.0 *vs* 4.5%, $p = 0.001$; refracture: 0.6 *vs* 3.8%, $p = 0.024$) (34).
Regarding periprosthetic distal femur fractures with stable implant several options are allowed; Ristevski et al. (35), in a systematic review providing a total of 719 fractures, showed that locked plating and retrograde intramedullary nailing offer significantly better results instead of conservative treatment and conventional plate; moreover, locking plate showed lower rates of malunion compared to retro-

Table 1 - UCS Classification and periprosthetic fractures treatment algorithm.

JOINT	BONE
I: Shoulder II: Elbow III: Wrist IV: Hip V: Knee VI: Ankle	1: Humerus 14: Glenoid/scapula 2: Radius/ulna 3: Femur 4: Tibia 34: Patella 6: Acetabulum/pelvis 7: Carpus/metacarpals 8: Talus
FRACTURE TYPE	**TREATMENT**
A ***A**pophyseal or extraarticular/periarticular* Subtypes • A1: Avulsion of (e.g. greater trochanter) • A2: Avulsion of (e.g. lesser trochanter)	Depends on displacement and importance of soft tissue attached, e.g.: • greater trochanter, tibial tuberosity, greater humeral tuberosity: surgical treatment • lesser trochanter, coracoid process: conservative treatment
B ***B**ed of the implant or around the implant* Subtypes • B1: Prosthesis stable, good bone • B2: Prosthesis loose, good bone • B3: Prosthesis loose, poor bone or bone defect	B1: Lower limb: reduction and fixation, LCP and if possible MIPO technique preferred. B1: Upper limb: depends on displacement, conservative treatment preferred. B2: Revision surgery. B3: Revision surgery that may require complex reconstruction (megaprosthesis, allograft/stem composite). Depends on the bone loss and age/activity of the patients.
C ***C**lear of or distant to the implant*	Same management as no-periprosthetic fracture.
D ***D**ividing the bone between two implants or interprosthetic or intercalary*	Decision-making depends on "block-out analysis"*. Subtype A (both prostheses stable): reduction and fixation Subtype B (one stable and one loose): revision surgery Subtype C (both loose):both joint revision surgery, total replacement
E ***E**ach of two bones supporting one arthroplasty or polyperiprosthetic*	Decision-making depends on "block-out analysis"* (e.g. separate assessment of femoral fracture with stem of THA and acetabular fracture with cup)
F ***F**acing and articulating with a hemiarthroplasty*	Depends on displacement, conservative treatment preferred.

***Block-out analysis= to analyze separately PF in relation with two joints.**

grade intramedullary nail but demonstrated no significant differences with regard to rates of nonunion (malunion: 7.6 *vs* 16.4%, p=0.02; nonunion: 8.8 *vs* 3.6%, p=0.05).

In contrast to fractures of the lower limb, humerus fractures are mostly conservatively treated. Neviaser et al. stated that periprosthetic humeral fractures with a well fixed implant and acceptable alignment can be managed nonoperatively (36). Kurowicki et al. (37) treated a series of 7 humeral PF (type B according to Wright and Cofield classification) using a locking plate with eccentrically placed screw holes; they reported a 100% union rate and excellent pain relief (mean visual analogic score of 0.5) at an average follow-up of 29 weeks.

In **Type B2** fractures the implant is loose but bone stock is preserved, and revision surgery is the preferred treatment choice (27, 38-41). A **Type B3** pattern is a B2 femoral fracture with poor bone stock that might require complex reconstruction or even a salvage procedure (megaprosthesis, allograft/stem composite). Munro et al. reviewed, at a mean follow-up of 54 months, 46 femoral PF Vancouver type B2 and B3 treated with modular tapered titanium stem. They found stem subsidence in 24% of cases but acceptable clinical results: Oxford score (76 of 100), WOMAC function and pain scores (75 and 82 of 100) (38). Neumann et al. reviewed 55 consecutive patients underwent revision surgery using a modular cement-less stem for femoral type B2/B3 fractures (39). The mean HHS postoperatively at 67 months' follow-up was 72 points (range, 45-97) and complete fracture union occurred in all patients three to six months after surgery.

Rasouli et al. (42) reviewed published reports about Vancouver type B3 femoral PFs and they recommended the

Table 2 - Outcomes for femoral periprosthetic fractures surgically treated.

Authors	Number of patients	Mean age at surgery (years)	Fracture type	Surgical treatment	Weight bearing	Follow up (months)	Union rate	Clinical outcome (mean points)	Complications
Neumann et al. 2011 (39)	55	74 (45–84)	B2: 35 B3: 20	Modular tapered stem	Partial weight bearing for 6 weeks. Full weight bearing at 3 months	67 (60–144)	100% at 6 months	Harris Hip Score 72(45–97)	Stem subsidence: 2 (4%) Nerve palsy: 1(2%) Reoperation: 2 (4%)
Munro et al. 2014 (38)	55	72 (44–93)	B2: 38 B3: 17	Modular tapered stem	Partial weight bearing for 6 weeks. Full weight bearing after complete healing	54 (24–143)	98% at 24 months	WOMAC score: 76	Infection: 1 (2%) Stem loosening: 1 (2%) Stem subsidence: 2 (4%) Dislocation: 2 (4%) Refracture: 2 (4%) Acetabular failure: 1 (2%) Emathoma: 1 (2%) Reoperation: 10 (18%)
Hoffman et al. 2016 (30)	51	78.7 (61–94)	B1: 33 C: 18	Locking compression plate (LCP)	Weight bearing delayed until callus formation.	25 (3–102)	90.2% (N/A)	N/A	Infection: 1 (2%) Non-union: 3 (5.9%) Fixation failure: 2 (4%) Malalignment: 5 (10.9%) Reoperation: 5 (9.8%)
Froberg et al. 2012 (29)	60	78 (49–97)	B1 C	Locking compression plate (LCP)	N/A	23 (0–121)	71,6% at 6 months	N/A	Infection: 4 (6.6%) Stem loosening: 1 (1.6%) Fixation failure: 3 (5%) Reoperation: 8(13.3%)
Yeo et al. 2015 (31)	17	74 (57–92)	B1	Locking compression plate (LCP) with cortical strut allograft	Partial weight bearing for 6 weeks. Full weight bearing after complete healing	28 (12–74)	100% at 5 months	Harris Hip Score 86 (77–95)	None
Platzer et al. 2011 (41)	22	79.2 (59–89)	D	Locking compression plate (LCP): 19 Modular tapered stem:4	Partial weight bearing for 6-8 weeks after plate fixation.	N/A	86% at 6 months	Harris Hip Score 78.4	Fixation failure: 4 (18%) Non-union:1 (4.5%) Reoperation:1 (4.5%)

Table 3 - Outcomes for periprosthetic fractures after TKA surgically treated.

Authors	Number of patients	Mean age at surgery (years)	Fracture type	Surgical treatment	Weight bearing	Follow up (months)	Union rate	Clinical outcome(mean points)	Complications
Platzer et al. 2010 (13)	41	78.6 (59-95)	Femur fracture:37 Type I: 11 Type II: 22 Type III:4 (*) Tibial fracture: 4 Type I:1 Type II:2 Type IV:4 (**)	Plate fixation: 18 Nail fixation: 15 Revision: 3 Nonoperative: 5	Stable fractures: gradual as tolerated. Unstable fractures: weight bearing delayed for 6-8 weeks.	N/A	61% at 6 months	N/A	Mortality: 3 (7%) Overall complication rate: 17(41%) Nonunion:5 (12%) Reoperation: 4 (9.7%)
Matlovich et al. 2017 (32)	55	75.5 (+/-10)	Type II (***)	Plate fixation: 38 Nail fixation: 19	Full weight bearing at 15 weeks	Plate fixation:15.6 (+/- 12.6) Nail fixation:13.9 (+/-15.7)	N/A	N/A	Nonunion: 2 (2.9%) Reoperation rate: 26.3% Nail fixation 2.7 % Plate fixation
Leino et al. 2014 (41)	68	79 (43-95)	Femur fracture: Type I:1 Type II:45 Type III:15 (***)	Plate fixation: 39 Revision: 29	Revision: immediate full weight bearing Plate fixation: partial weight bearing for 6 weeks	29.9 (0.1-89.1)	N/A	N/A	Infection:7 (10.3%) Nonunion: 6 (8.8%) Patellar dislocation: 3 (4.4%)

(*) Su et al. Classification, (**) Felix et al. Classification (24), (***) Rorabeck Classification (23)

Table 4 - Outcomes for humeral periprostethic fractures surgically treated.

Authors	Number of patients	Mean age at surgery (years)	Fracture type	Surgical treatment	Aftercare	Follow up (months)	Union rate	Clinical outcome(mean points)	Complications
Kurowicki et al. 2016 (37)	5	74(52-88)	Type B (*)	Plate fixation	Shoulder immobilization for 4 weeks.	29(12-48)	100% at 53 weeks	ASES score: 75 (62-100) ASES Function Score:28 (15-50) Simple Shoulder Test:7 (3-11)	Infection: 1 (20%)
Mineo et al. 2013 (33)	7	72.1 (68-75)	Type C(*)	Plate fixation	N/A	N/A	100% at 6 months	N/A	N/A
Sewell et at. 2012 (40)	22	75 (61-90)	N/A	Revision surgery	N/A	42 (12-91)	100% at 23.5 months	Oxford Shoulder Score: 25 (9-13)	Dislocations:2 (9.1%) Modular component dissociation:1 (4.5%) Nonunion:1 (4.5%) Prominent screw:1 (4.5%) Infection:1 (4.5%) Nerve palsy:2 (9.1%)

(*) Wright and Colfield Classification (25)

use of allograft composite prosthesis in young and active patients and proximal femoral replacement in older and less active patients. In spite of the high rate of overall complications with these two procedures, they reported acceptable survivorship rates ranging from 74% to 89% at 2 to 15 years' follow-up. Bhattacharyya et al. (9) showed that revision surgery (12%) in Vancouver type B fractures is associated with significant lower mortality ratio than ORIF (33%; p <0.03).

Type C fracture is distal to the implant and can be treated according to AO/OTA surgical fixation principles (27).

Type D are also known as Interprosthetic fractures. The correct preoperative planning involves the study of fracture pattern of the two joint individually, the so-called "block-out analysis". Treatment is extremely variable (conservative, ORIF, revision surgery of one or both joints involved) and depends on stability of the implants. Three subtypes of interprosthetic fractures have been described according to Solarino et al. (43): subtype A (both prostheses stable), subtype B (one stable and one loose), subtype C (both loose). Platzer et al. reported results of 19 interprosthetic femoral fractures with both stable implants, treated successfully with ORIF; they found 86% fracture healing achieved at 6 months, mean Harris Hip Score of 78.4 points and Knee injury and osteoarthritis outcome score of 71.8 points (44).

Type E is a fracture of each of two bones supporting one arthroplasty or polyperiprosthetic; the "block out analysis" concept is the same required to be used in D fractures.

Type F are fractures of a joint surface which is not replaced but is articulated with an implant (i.e. acetabulum or glenoid in hemiarthroplasty, patella in TKA without patella resurfacing). In Type F fractures decision-making is related to implant displacement and conservative treatment is preferred when achievable.

Pharmacological treatment

Severe osteoporosis affects the majority of patients with a PF. Furthermore, age, comorbidities and prolonged immobilization, justify the long healing time, with higher nonunion and complications rates after PF.

Therefore, the "Diamond concept" for fracture healing, should be taken in consideration in PF as well as in all other fragility fractures (45). According to this theory, the osteogenesis process in bone union, can be supported by the implantation of mesenchymal stem cells, scaffolds and growth factors in the fracture bed. Additionally, the surgical procedure should provide the appropriate mechanical and biological environment, the so-called "biological chamber", in order to efficiently enhance the physiological healing process. The "Diamond Concept" has later evolved into the "Pentagon Concept", including adjuvant multiple systemic pharmacological treatment (anti-resorptive and anabolic drugs) as key-role therapy to enhance bone metabolism (46).

Systemic treatment for fracture healing is described only in small series with encouraging results, but large RCTs are required in order to prove their validity (47).

Kim et al. reported the use of teriparatide in challenging cases as femoral PF, atypical fractures and nonunion (48). In their series, the mean time to clinical union was recorded as 5.7 months, and the median time to radiological union was recorded as 5.4 months. From 2009 we began to surgically treat femoral PF with ORIF or stem revision in association with pharmacological anabolic treatment (teriparatide or strontium ranelate) (49). The results at 2-year minimum follow-up showed satisfying clinical results. The mean HHS score was 84 points (range, 76 - 88) with a mean 97.7° of flexion (range, 90 - 100). All the patients achieved full weight bearing at 3 months after surgery. The mean radiological healing time was 4 months in patients treated with ORIF and 3.5 months in patients who underwent stem revision surgery.

Conclusions

Despite all efforts periprosthetic fractures are still an emergent problem associated to high rates of morbidity and mortality. The prevention of PF through radiological surveillance is crucial in order to detect early signs of implant loosening and lack of stability. Moreover, other well known risk factors, as osteoporosis, should be properly and preventively treated.
A comprehensive treatment algorithm should allow to fully understand the personality of the fracture. Besides local criteria (as location, stability and bone loss), PF treatment options should be influenced by systemic factors as age of the patient, activity level, bone metabolism and major/minor comorbidities. In summary, the combination of mechanical stability obtained by modern surgical techniques associated with pharmacological systemic treatment seems to be the path to take in the future.

References

1. Kurtz S, Ong KL, Lau E, et al. Projections of primary and revision hip and knee arthoplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89(4):780-785.
2. Day JS, Laue E, Ong KL, et al. Prevalence and projections of total shoulder and elbow arthoplasties in the United States to 2015. J Shoulder Elbow Surg. 2010;19(8):1115-1120.
3. Della Rocca GJ, Leung KS, Pape HC. Periprosthetic fractures: epidemiology and future projections. J Orthop Trauma. 2011;25:S66-S70.
4. Hasegawa K, Kabata T, Kajino Y, et al. Periprosthetic occult fractures of the acetabulum occur frequently during primary THA. ClinOrthopRelat Res. 2016.
5. Abdel MP, Watts CD, Houdek MT, et al. Epidemiology of periprosthetic fracture of the femur in 32664 primary total hip arthroplasties. Bone Joint J. 2016;98-B:416-417.
6. Delasotta LA, Orozco F, Miller AG, Post Z, Ong A. Distal femoral fracture during primary total knee arthroplasty. J Orthop Surg (Hong Kong). 2015 Aug;23(2):202-204.
7. Toogood PA, Vail TP. Periprosthetic Fractures. A Common Problem with a Disproportionately High Impact on Healthcare Resources. J Arthroplasty. 2015;30(10):1688-1691.
8. Drew JM, Griffin WL, Odum SM, et al. Survivorship after periprosthetic femur fracture: factors affecting outcome. The Journal of Arthroplasty. 2016;31:1283-1288.
9. Bhattacharyya T, Chang D, Meigs JB, et al. Mortality after periprosthetic fracture of the femur. J Bone Joint Surg Am. 2007;89(12):2658-62.
10. Zheng L, Lee WL, Hwang DS, et al. Could patients underwent surgical treatment for periprosthetic fracture after hip arthroplasty return to their status before trauma? Hip Pelvis. 2016;28(2):90-97.
11. Lindahl H, Garellick G, Regnér H, et al. Three hundred and twenty-one periprosthetic femoral fractures.J Bone Joint Surg Am. 2006;88(6):1215-1222.
12. Campbell JT, Moore RS, Iannotti JP, et al. Periprosthetic humeral fractures: Mechanisms of fracture and treatment opinions. J Shoulder Elbow Surg. 1998;7(4):406-413.
13. Platzer P, Schuster R, Aldrian S, et al. Management and outcome of periprosthetic fractures after total knee arthroplasty. J Trauma. 2010;68:1464-1470.
14. Singh JA, Sperling J, Schleck C, et al. Periprosthetic fracture s associated with primary total shoulder arthroplasty and primary humeral head replacement. J Bone Joint Surg Am. 2012;94:1777-1785.
15. Abdel MP, Houdek MT, Watts CD, et al. Epidemiology of periprosthetic femoral fractures in 5417 revision total hip arthroplasties. Bone Joint J. 2016;98-B:468-474.
16. Zhang Z, Zhuo Q, Chai W, et al. Clinical characteristics and risk factors of periprosthetic femoral fractures associated with hip arthroplasty. Medicine. 2016;95:35.
17. Yoo JD, Kim NK. Periprosthetic fractures following total knee arthroplasty. Knee Surg Relat Res. 2015;27(1):1-9.
18. Haidukewych G, Jacofsky DJ, Hanssen AD, et al. Intraoperative fractures of the acetabulum during primary total hip arthroplasty. J Bone Joint Surg Am. 2006;88(9):1952-1956.
19. Chitre A, Jones HW, Shah N, et al. Complications of total hip arthroplasty: periprosthetic fractures of the acetabulum. Curr Rev Musculoskelet Med. 2013;6:357-363.
20. Watts CD, Abdel MP, Lewallen DG, et al. Increased risk of periprosthetic femur fractures associated with a unique cementless stem design. Clin Orthop Relat Res. 2015;473:2045-2053.
21. Alden KJ, Duncan WH, Trousdale RT, Pagnano MW, Haidukewych GJ. Intraoperative fracture during primary total kneearthroplasty. Clin Orthop Relat Res. 2010;468:90-95.
22. Duncan CP, Masri BA. Fractures of the femur after hip replacement. Instr Course Lect. 1995;44:293-304.
23. Rorabeck CH, Taylor JW. Classification of periprosthetic fractures complicating total knee arthroplasty. Orthop Clin North Am. 1999;30:209-214.
24. Felix NA, Stuart MJ, Hanssen AD. Periprosthetic fractures of the tibia associated with total knee arthroplasty. Clin Orthop Relat Res. 1997; 345:113-124.
25. Wright TW, Cofield RH. Humeral fractures after shoulder arthroplasty. J Bone Joint Surg Am. 1995;77:1340-1346.
26. Naqvi GA, Saig SA, Awan N, et al. Interobserver and intraobserver reliability and validity of the Vancouver classification system of periprosthetic femoral fractures after hip arthroplasty. J Arthroplasty. 2012; 7:1047-1050.
27. Duncan CP, Haddad FS. The Unified Classification system (UCS): improving our understanding of periprosthetic fractures. Bone Joint J. 2014;96-B:713-716.
28. Viorenau MH, Parry MC, Haddad FS, et al. Field testing the Unified Classification System for peri-prosthetic fractures of the pelvis and femur around a total hip replacement. Bone Joint J. 2014;95-B;1472-1477.
29. Froberg L, Troelsen A, Brix M. Periprosthetic Vancouver B1 and C fractures treated by locking-plate osteosyntesis. Acta Orthopaedica. 2012;83(6):648-652.
30. Hoffman MF, Lotzien S, Schildhauer TA. Outcome of periprosthetic femoral fractures following total hip replacement treated with polyaxial locking plate. Eur J Orthop Surg Traumatol. 2017;27(1):107-112.
31. Yeo I, Rhyiu KH, Kim SM, et al. High union rates of locking compression plating with cortical strut allograft for type B1 periprosthetic femoral fractures. International Orthopaedics (SICOT). 2016;40:2365-2371.
32. Matlovich NF, Lanting BA, Vasarhelti EM, et al. Outcomes of surgical management of supracondylar periprosthetic femur fractures. The journal of arthroplasty. 2017;32:189-192.
33. Mineo GV, Accetta R, Franceschini M, et al. Managment of shoulder periprosthetic fractures: Our institutional experience and review of the literature. Injury, Int J Care Injured. 2013;44:S1, S82-S85.
34. Stoffel K, Sommer C, Kalampoki V, et al. The influence of the operation technique and implant used in the treatment of periprosthetic hip and Interprosthetic femur fractures: a systematic literature review of 1571 cases. Arch Orthop Trauma Surg. 2016;136:553-561.
35. Ristevski B, Nauth A, Williams DS, et al. Systematic review of the treatment of periprosthetic distal femur fractures. J Orthop Trauma. 2014;28:307-312.
36. Neviaser AS, Flatow E. Periprosthetic humeral fractures: you're breakin' my heart. Semin Arthro. 2011;22:48-50.
37. Kurowicki J, Momoh E, Levy JC. Treatment of Periprosthetic humerus

fractures with open reduction and internal fixation. J Orthop Trauma. 2016;30:e369-e374.
38. Munro J, Garbutz DS, Masri BA. Tapered fluted titanium stems in the management of Vancouver B2 and B3 periprosthetic femoral fractures. Clin Orthop Relat Res. 2014;472:590-598.
39. Neumann D, Thaler C, Dorn U, et al. Management of Vancouver B2 and B3 femoral periprosthetic fractures using a modular cementless stem without allografting. International Orthopaedics. 2012;36:1045-1050.
40. Sewell MD, Kang SN, Al-Hadithy N, et al. Management of periprosthetic fracture of the humerus with severe bone loss and loosening of the humeral component after total shoulder replacement. J Bone Joint Surg Br. 2012;94(10):1382-1389.
41. Leino OK, Lampainen L, Virolainen P, et al. Operative results of periprosthetic fractures of the distal femur in a single academic unit. Scand J Surg. 2014;104:200-207.
42. Rasouli MR, Porat MD, Hozack WJ, et al. Proximal femoral replacement and allograft prosthesis composite in the treatment of periprosthetic fractures with significant proximal bone loss. Orthopaedic Surgery. 2012;4:203-210.
43. Solarino G, Vicenti G, Moretti A, et al. Interprosthetic femoral fractures. A challenge of treatment. A systematic review of the literature. Injury. Int J Care Injured. 2014;45:362-368.
44. Platzer P, Schuster R, Luxl M, et al. Management and outcome of interprosthetic femoral fractures. Injury, Int. J. Care Injured. 2012;42:1219-1225.
45. Giannoudis PV, Einhorn TA, Marsh D. Fracture healing: The diamond concept. Injury, Int. J. Care Injured. 2007;38S4:S3-S6.
46. Brandi ML. Healing of the bones with anti-fracture drugs. Expert Opin Pharmacoter. 2013;14(11):1441-1447.
47. Vannucci L, Brandi ML. Healing of the bones with anti-fracture drugs. Expert Opin Pharmacoter. 2016;17:17, 2267-2272.
48. Kim JT, Jeong HJ, Lee SJ, et al. Adjuvant Teriparatide therapy for surgical treatment of femoral fractures; does it work?
49. Capone A, Ennas F, Podda D. Periprosthetic femoral fractures: risk factors and current option to tratment. Aging Clin Exp Res. 2011;23(2): 35-35.