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Review Article

Femoral neck fractures secondary to renal osteodystrophy. Literature review and treatment algorithm

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Abstract

Pathological fractures after minor trauma in osteopenic patients are not uncommon, but fractures due to hypocalcemic convulsions in patients with renal insufficiency are relatively rare. Though similar cases have been reported in the literature, this type of fracture is still an unusual condition. The complex underlying pathophysiological mechanisms and the poor bone mineral density signify the employment of specific hardware and a different treatment approach, especially in young adults, where the salvage of the femoral head is of utmost importance. The aim of this review is to examine the specific features of the femoral neck fractures in young individuals who suffer from renal osteodystrophy and the treatment algorithm should be followed. The patient's age, the uremic condition, the skeletal maturity and the bone properties in renal osteodystrophy are examined in relation to the priorities in osteosynthesis methods. A conclusive treatment algorithm is proposed where all the relevant parameters are incorporated.

Keywords: Femoral Neck Fracture, Tetanic Convulsions, Renal Osteodystrophy, Young Adults, Osteopenia

Introduction

The femoral neck is a biomechanically vulnerable area and therefore a common site of fractures when the bone is subjected to unusual loads as it is in the case of high energy trauma. Although the latter is the most common scenario, such unusual loads can be generated by excessive muscle contractions as well. This could happen during epileptic convulsions or during the course of electroshock therapy[1]. Certain medical conditions may further increase the possibility of such a rare fracture mechanism by diminishing bone strength. One of these is Renal Osteodystrophy (ROD). In patients suffering from this condition, the combination of uremia and hypocalcemia can lead to bone demineralization and severe osteomalacia. At the same time hypocalcemic tetanic convulsions can expose bone to the above mentioned unusual stresses resulting in pathologic fractures. The majority of these seizures occur during the dialysis sessions or in the immediate postoperative period following subtotal parathyroidectomy[1-6]. Although patients suffering either bilateral scapula fractures or bilateral femoral neck fracture in the above mentioned settings have been reported in the literature[1-5,7-15], there is still lack of recommendations regarding the treatment of these fractures.

The aim of this review is to examine the pathophysiology of insufficiency fractures due to renal osteodystrophy and the treatment options in such poor bone quality conditions in relation to the existing literature on this subject. Finally a conclusive treatment algorithm is suggested.

Data analysis

There only few studies in the literature that evaluate the effects of this type of hip fracture and its treatment approach in patients with end stage renal disease. The study of Karaeminogullari et al.[16] analyses the surgically treated hip fractures in patient under chronic hemodialysis. The mean age of patients with hip fractures was 57 years, ranging from 19 to 81 years. Nine out of thirteen femoral neck fractures, which were treated with cannulated screws, resulted in nonunion after biological and further mechanical failure. This was explained by the low bone quality, due to the severe osteoporosis and the ROD the patients had. The authors

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concluded that an arthroplasty is recommended for displaced femoral neck fractures in patients under hemodialysis. The latter is a reasonable conclusion but it cannot be applied in young patients with chronic renal failure.

Evaluating the operative treatment of hip fractures in hemodialysed patients, Sano et al.[17] supported that such fractures should be internally fixed if the patients are younger than 70 years of age. Instead they preferred arthroplasty because the former surgical option would take time for dialysed patients to reach bone union and it would be very likely to develop pseudarthrosis.

At five different case reports six young patients with ages ranging between 18 and 40 years had identical lesions[1-4,18]. They all suffered from femoral neck fractures due to hypocalcemic convulsions. Interestingly, every one of them received different treatment than the other. They were treated either with hemiarthroplasty or internal osteosynthesis. The later included options such as dynamic hip screw (DHS) and Knowles pins. Conservative management was preferred in one patient was. Most of the patients who were treated surgically had good results. Weight bearing was prohibited for a period of two to three months. Two patients treated with Knowles pins developed osteonecrosis of the femoral head (ONFH).

None of these reports but one[18], mentioned the way this type of lesions should be approached and treated in respect to the age, initial trauma, life expectancy, and the femoral head salvage of the patient. The authors concluded that the optimal approach of these fractures is the one recommended for the traumatic fractures diagnosed late, which is a stable fixation with either a pedicled graft or a vascularized fibular graft.

Pathophysiology

The hip is an area where the torque of powerful opposing muscles is well balanced. The center of the femoral head is the center of rotation of the femoral joint and the neck serves as the lever arm which carries all the acting muscle and weight bearing forces. Any condition leading to the deterioration of the bone structure or quality makes this area susceptible to fractures. Osteopenia resulting from chronic metabolic diseases such as secondary hyperparathyroidism and ROD is such an example. In comparison to osteoporosis in adults, where bone has decreased BMD with Z-score below -2.5, osteopenia in children and young adults can be greater than osteoporosis with a Z-score of -6[1].

Pathological femoral neck fractures occurring after hypocalcemic convulsions display a similar pattern. They are usually vertical neck or basal neck fractures, corresponding to types II and III of Pauwels classification system[19,20]. The more vertical the neck fracture line is, the stronger the shearing forces acting at the fracture site. Unless the chosen operative method takes into account this biomechanical property of the fracture the osteosynthesis will ultimately fail and lead to a non union or pseudarthrosis[19,21].

General treatment principles

The general treatment regime for these fractures dictates internal fixation for all undisplaced or displaced fractures of the femoral head with good bone stock. Thius can be accomplished either by closed or open reduction if necessary. Preferred methods include cannulated screws, Knowles pins or DHS with or without an antirotator screw[2,22,23]. In the case of older patients with underlying hip disease, cemented hemiarthroplasty or total hip arthroplasty, are strongly recommended[22]. In patients suffering from of metabolic bone disease (e.g. Paget disease), rheumatoid arthritis or neuromuscular disorders, hemiarthroplasty or total hip arthroplasty are indicated[20,23]. A cemented femoral prosthesis is preferred because a porous coated femoral stem used for press-fit fixation is not expected to be well incorporated. On the contrary, the acetabular component should be press fit[20].

Young adults

The pre-injury status and life expectancy are key factors when deciding whether to proceed with internal fixation or hip joint reconstruction[24]. Although prosthetic replacement allows the patient to ambulate early postoperatively, comprises the risks of loosening of the prosthesis and subsequent revision surgery. In a meta-analysis of 106 reports pertaining to femoral neck fracture, Lu-Yao et al.[25] showed that although internal fixation is associated with a higher failure rate, it offers the long-term chance of regaining normal function of the hip. In the case of primary bone disease at young age in a patient with normal life expectancy the use of a hip prosthesis is not an option[26]. The rationale in treating such fractures in young adults is to choose the least invasive procedure in order to retain the maximum of bone stock keeping always in mind the possibility of future revision surgery[23].

Uremic patients

In uremic patients with ROD or secondary hyperparathyroidism the bone quality is diminished and lacks in mineral content, which is reflected by the low bone mineral density (BMD). Since the BMD correlates linearly with the screws holding power, implant pull out is easier[24,27-29]. The osteodystrophic bone has altered biochemical constitution and therefore reduced strain tolerance to the loads transmitted to it by the implant. The reduced bone adaptation leads to periprosthetic microfractures and finally loosening of the implant.

Failure of osteosynthesis in osteodystrophic situations is a consequence not only of poor bone quality but also of inappropriate surgical technique. In the study by Weinrobe et al.[21] the fracture geometry, the bone density, and the reduction were examined in relation to the redisplacement of a femoral neck fractures fixed with cancellous screws. The authors stated that among the factors examined, the dual energy X-ray absorbtiometry (DEXA) bone density score of

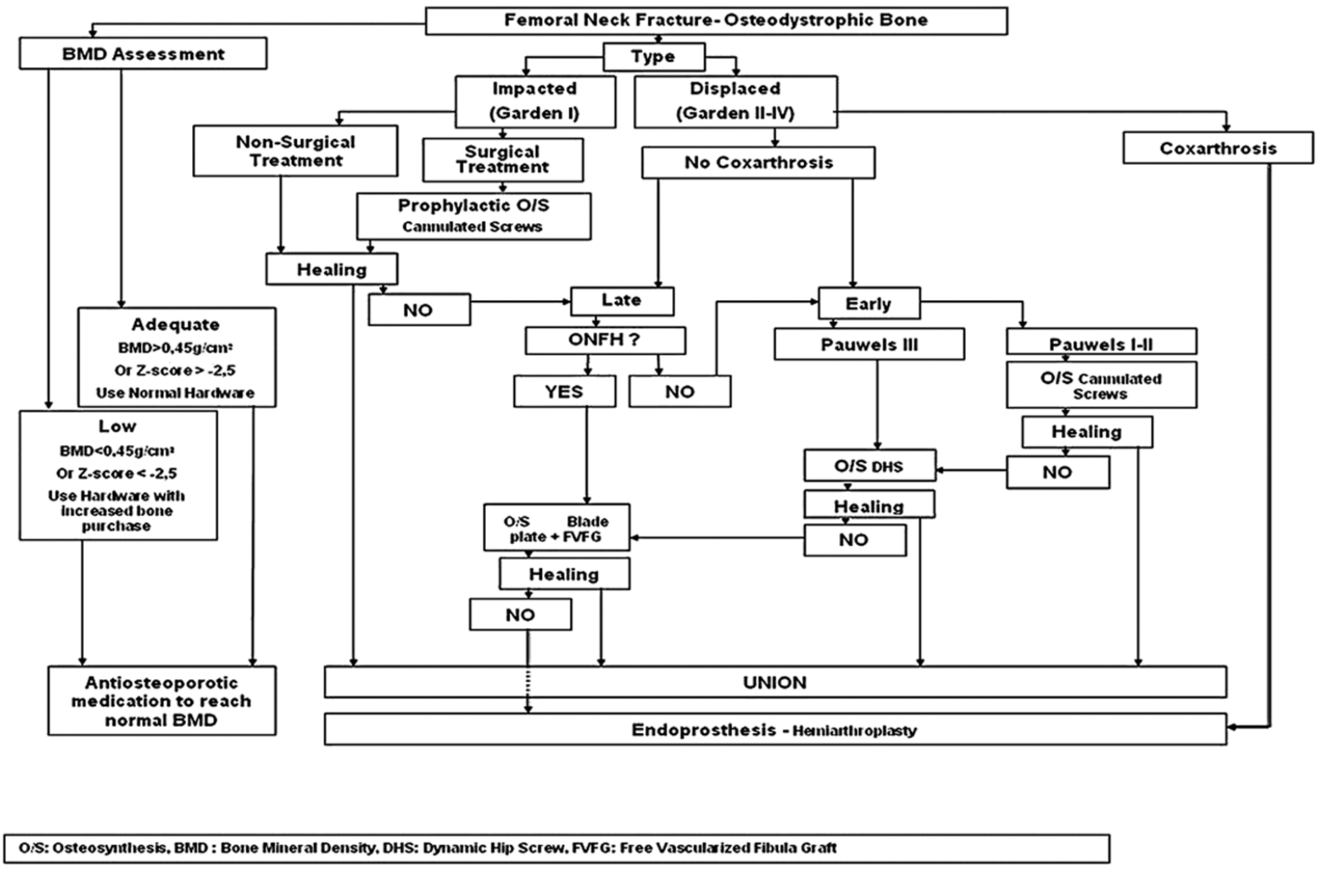

Figure 1. Suggested approach for the treatment of femoral neck fractures in young adults with osteopenic bones due to renal osteodystrophy.

1. The patient must be evaluated for comorbidities, for eliminating the possibility of this being a pathologic fracture of different cause and the pre-injury hip function.
2. Full evaluation of the underlying bone disease must be made and the proper treatment should be administered.
3. An attempt to internally fixate the femoral neck fractures should be made.
4. Certain points must be highlighted at the surgical technique:
   i) All surgical manoeuvres of reduction and fixation must proceed cautiously in order to avoid the further comminution of the fragile osteopenic bone.
   ii) If the fracture has no comminution at all the perfect anatomic reduction must be sought. If there is any comminution the fracture must be reduced in a valgus position.
   iii) Three of four cannulated screws must be used. The inferior cannulated screw must be in contact with the distal cortex of the femoral neck in order to buttress and to prevent the tendency of the head to fall into a varus position when loaded.
   iv) If the BMD is below 0,45g/cm^2 or the Z-score is less than -2.5 then the bone-implant stability and strength should be increased by:
      a) Using longer implants (plate or rod) for broader load transfer and for avoiding failure at the bone-implant junction.
      b) Using additional screws (cortical or locking ones) when plating, to distribute the force over a greater area.
      c) Using locking plates and screws to create a stiffer hardware construct
      d) Introducing the screws in different directions (not parallel to each other) to increase the pullout strength.
      e) Using fixed-angled devices which prevent pull-out.
      f) Collo diaphyseal plates, talon nails and/or screws with wider thread diameter or covered with HA, which have a better grip on the osteopenic trabecular bone.
      g) The osteopenic bone can be augmented at certain areas with the use of PMMA or biodegradable calcium phosphate bone substitutes for better hardware grip.
5. If the first osteosynthesis fails a second may be attempted following the same guidelines with a slightly extended exposure to use 'healthy' bone.
6. In case of a pseudarthrosis bone grafts and/or BMP's can be used to enhance the bone healing
7. If the femoral neck fracture leads to ONFH, a revision osteosynthesis can be performed with the use of a vascularized fibula graft for supporting both the fracture healing and the vitality of the femoral head.
8. If all the above options fail in the young patient, there would still be sufficient bone stock for a hemiarthroplasty.
9. If a coxarthrosis existed prior to the femoral neck fracture or if there is an advanced stage ONFH, the salvage of the femoral head is pointless and a hemiarthroplasty must be performed.
10. Careful mobilization and minimal weight bearing should be followed until the BMD value is increased to nearly normal levels.

less than 0.65 g/cm^2 was a less significant predictor of fracture redisplacement. This seemed a reasonable conclusion since patients with no metabolic bone disease and a mean age of 63.9 years were examined. They also commented that if the bone density is too low then this might also be a predictor of fracture redisplacement. Hence, the bone density is considered to be of greater importance if the femoral neck fracture to be treated has an underlying ROD.

Implants used for fracture treatment of deficient bone

Implants designed for fracture treatment were originally developed for patients with sufficient bone quality[26]. Although the preoperative BMD values are not necessary for the selection between DHS or cannulated screws for the treatment of femoral neck fractures, it seems to be related with the initial intrinsic fixation and the further fixation success[30-33].

In patients with ROD, bone displays abnormal biomechanical parameters and it is much weaker and brittle, making it more difficult to achieve a stable implant-bone construct required for fracture fixation (Figure 1)[34]. One of the main problems in femoral neck fracture fixation is the displacement of the fractured bone fragment. Apart from the thorough reduction and osteosynthesis, bone quality is the main parameter influencing maintenance of the achieved reduction over time[31,35]. Higher bone density results in more stable intrinsic fixation initially[30].

More "bone protective" and relative stability techniques reduce the risk of failure at the bone-implant interface. The development of new load sharing implants, which distribute the loads smoothly over a much greater bone area as well as other solutions, such as the use of new alloys or material coverings, give rise to better fixation to bone of inferior quality[36]. Modifications of conventional fixation devices can be used for osteodystrophic bones.

Cannulated screws with larger thread diameter can be used for better grip in the sparse trabecular bone[35,37]. Fixed-angle devices have broad load-bearing areas and they show resistance to angular deformation and torsion[29,34,38-41]. The locking compression plates (LCP) create a fixed screw-implant construct with low bone-implant interface strain. The pull out strength of the LCP implant is high, because all the screws must simultaneously fail in order to detach from the bone[42,43]. This strength can be further improved by inserting the screws in multiple fixed angles[44]. Dynamic hip screw with longer plate for wider load distribution is also available[29]. In multiple studies comparing internal fixation materials, it was shown that the DHS combined with an antirotator screw offers the best holding power in intracapsular, bone deficient femoral neck fractures[36,45].

Szita et al.[35], developed a custom dynamic collo-diaphyseal plate (DCD), which provides a fixed-angle sliding screw construct and is indicated in multi-fragmentary, comminuted or stress fractures. With the aid of an additional screw it can also be used in rotationally unstable fractures as well. The bone quality in renal osteodystrophy resembles that of the osteopenic bone of an older person. Although the metabolic rate of the bone in osteomalacia is high, it fails to provide the proper strength and is prone to same type of stress fractures occur when remodeling mechanisms fail to keep up with excessive local bone damage. Therefore, the DCD device can effectively be used in osteodystrophic fractures.

Hydroxyapatite (HA) coated screws seem to have better bone-material incorporation in comparison to normal-uncoated screws[46]. Simultaneous systemic biphosphonate administration doubles the anchorage strength[47]. These coatings can also be used as drug delivery systems for other substances, such as biphosphonates, bone morphogenetic proteins (BMP), etc. Careful pre-tensioning of the fixation device such as the DHS may prevent the secondary bone impaction[48], however it can not be applied at maximum strength because the cancellous bone will fail and then the grip of the sliding screw will be obliterated.

The longer plate of a DHS may contribute to wider load distribution but the sliding screw still has the disadvantage of fixating a sparse cancellous area. This can lead to migration of the femoral head in varus position and finally to cut out of the screw. Accurate screw placement by correctly measuring the tip-apex distance is the key to avoid such a complication[48]. In the same line of thought are some techniques used for enhancement of the sliding screw grip strength.

A cannulated screw modification has side openings for injectable substances to be advanced through its holes into the cancellous bone area[49]. Bioabsorbable cement can be injected to the fracture site in order to fill the fracture void and to augment the bone around the screw threads enhancing the holding characteristics in the femoral head. This can lead to better stability in the cement-augmented fractures with less overall movement, less distal migration of the femoral head fragment, and less varus angulation during early rehabilitation[41,50-52].

Polymethylmethacrylate (PMMA) cement is being used for the same purpose and is also showing good results in increasing the sliding screw anchorage. This cement can be delivered either by the way of the bioabsorbable cement or via a modified for this purpose hip screw[41,53-56]. The latter spreads the cement exactly at the fixation point and avoids the interposition between the fracture surfaces. Although these solutions are mentioned in the treatment of trochanteric fractures, they can also be applied in femoral neck fractures by diminishing the cement quantity and by careful intraoperative image intensifier inspection during the cement introduction.

Another modification is the Talon compression hip screw, which increases anchorage with its removable four talons in the femoral head area[57]. This has been described for osteoporotic intertrochanteric fractures, but it can also be applied to femoral neck fractures. Apart from the increased interfragmental compression it provides better torsional strength comparing to the standard DHS.

Surgical technique

A surgical technique that relies only on the type of implant produces poor results[30,58]. In a study by Weinrobe et al.[21] the fracture geometry, the bone density, and the fracture reduction are examined in relation with the redisplacement of a femoral neck fracture fixed with cancellous screws. The authors stated that the two measures: i) the angle formed by the axis of the femoral head/neck proximal fracture component and the axis of the remaining region of the femoral neck, and ii) the offset of the femoral head fracture component cortex with respect to femoral neck cortex, were found to be the strongest predictors of no loss of reduction postoperatively. Another, less significant, predictor was the femoral fracture angle respect to the axis of the femoral shaft. Fracture surfaces with angles less than 41.6 degrees from the femoral shaft axis redisplaced at a higher rate than those with angles greater than 41.6 degrees (Pauwels I-II). Hence, the perfect anatomic reduction should be sought in a deficient bone.

The bone density of the head is usually greater than that of the femoral neck. When a compressive load is applied to the femoral head, as in ambulation, the head tends to displace inferiorly and rotate into a varus position. The bone of the femoral neck inferior to the screw shafts (the Ward's triangle area) is not effective in preventing the screws from rotating into varus leading to screw pullout and finally to failure of osteosynthesis. However, when the inferior screw is placed close to the inferior cortex of the femoral neck, it is buttressed and resists rotation, and the effect of bone density is lessened. Therefore, surgical technique has a part to play in the role of bone density on fracture redisplacement.

Cannulated cancellous bone screws or compression hip screws were recommended for the treatment of femoral neck fractures. The three-point fixation principle for the introduction of cannulated screws was stated and the position of the compression hip screw for steep fracture angles above 50° (Pauwels III) was recommended[21,30].

In the study by Levi et al.[58] it is mentioned that the optimal position of the sliding screw is the inferoposterior position of the centre of the femoral head, where the bone has the maximum BMD[36].

In osteopenic young patients with femoral neck fractures, a valgus osteotomy and internal fixation with either a DHS or an angular blade plate is recommended[23,59,60]. Osteosynthesis in valgus reduction was achieved using a wide angle DHS plate in a 30-year-old female patient, who suffered bilateral femoral neck fractures caused by tetanic convulsions[10]. Uremic young adults, at the borderline of skeletal maturity differ in that they demonstrate delayed physeal ossification[6]. These patients may present with child-specific lesions, such as slipped femoral epiphysis[3]. The treatment in these cases should be adjusted so as to match protocols followed in younger ages[3].

The role of BMD

There is a debate about the preoperative assessment of the BMD. It may not be considered essential for choosing of the type of osteosynthesis, but in the cases of renal osteodystrophy where the DEXA value often reaches lower limits than these of osteoporosis, it may play a major role for the fixation success (Figure 1)[21,25,30-33,37,58,61]. Although several minimal DEXA values have been published as to be critical for a secure osteosynthesis, still does not exist a certain bone mineral density below which the osteosynthesis would be considered insufficient[21,31,36]. Values of less than 0.45 g/cm^2 generally indicate the magnitude of bone loss and may guide the surgeon to more "bone protective" solutions and to a more precise osteosynthesis. The former can also serve as a marker of the further improvement of the underlying bone disease of the patient[30]. Careful mobilization and minimal weight bearing should be followed until this BMD value is increased to nearly normal levels. The young patient with osteopenic fracture, in contradiction to the older patient with an osteoporotic fracture, is able to follow the limited weight bearing instructions.

Postoperative management

The greatest femoral neck fracture fragment movement occurs during the first postoperative month[21,61]. In osteopenic patients with metabolic bone disease the bone potential is low and the healing process prolonged[24]. The fracture callus usually does not form normally and healing occurs slowly as a result of delayed mineralization[18].

Young adults with such pathology and femoral neck fixated fractures should be prevented from weight bearing for a period of 12 weeks or longer (8-12 wks in healthy individuals), depending on the radiographic assessment of the healing process[29].

Prior to any operative approach, a correct assessment of the underlying bone disease should be done. A treatment regimen is planned aiming to regain normal or near-normal bone mass. Once the medical treatment is started, there is generally little problem with bone healing and union occurs fairly rapidly, except perhaps in patients with hypophosphatasia[18]. This is accomplished by conservative means, such as oral nutritional supplements containing calcium, vitamin D, or biphosphonates[30]. When indicated operative procedures, such as subtotal parathyroidectomy or renal transplantation can permanently cure the underlying disease. Amyloidosis, hypogonadism, avascular necrosis, chronic acidosis or other conditions, that may play role in the pathogenesis of reduced bone mass in these patients, should also be excluded[62].

Complications

Knowledge of the potential complications according to the fracture type or the treatment modality used is essential in order to choose the correct primary osteosynthesis. Preservation of the femoral head is of utmost importance in young patients[60]. Non-union happens in 10% of all cases and is relevant to the advanced Pauwels types, the underlying bone disease, the osteosynthesis type and the postoperative mobilization protocol. The probability of ONFH depends on the initial injury force, the displacement of the fracture, the time interval between the injury and the final fixation, and the fixation method used (open, closed reduction, osteosynthesis materials). Osteonecrosis develops in 11-18% of all neck fractures in ROD[5,36]. Even though ONFH is not a contraindication for internal fixation, it will most likely lead to femoral head collapse, if after fracture union it is subjected to normal loads.

In case of nonunion, pseudarthrosis or a failed osteosynthesis, bone grafts or BMP's can be used to enhance the healing process. A revision of the same or any other of above mentioned osteosynthesis methods can be performed leaving the conversion to hemiarthroplasty or total hip arthroplasty as the last option[60,63]. A pedicled autograft described by Judet and Meyers reinforces the nonunion site, but has less efficacy in revitalizing the femoral head[64]. In case of a concomitant ONFH a vascularized fibular autograft can be applied with the support of an angular blade plate. This option is a demanding operation suited for carefully selected patients, which has shown good results in terms of the long term preservation of the femoral head[65,66]. In contrast to this salvage procedure a bipolar cemented hemiarthroplasty was used in neglected bilateral femoral neck fractures in a 24 year old female with osteodystrophy after hypocalcemic seizures[5].

Conclusion

The goals of surgical treatment of femoral neck fractures in young adults with renal osteodystrophy and osteopenic bone are: i) to salvage the femoral head, ii) to achieve in every case a stable fixation, iii) not to harm the physeal plate if present, iv) to retain the maximum bone stock possible, and v) to return to normal activities as soon as possible. If the first osteosynthesis fails a second may be attempted following the same guidelines with a slightly extended exposure to use 'healthy' bone. In case of a pseudarthrosis bone grafts and/or BMP's can be used to enhance the bone healing In case of osteonecrosis, a revision osteosynthesis can be performed with the use of a vascularized fibula graft for supporting both the fracture healing and the vitality of the femoral head. If a coxarthrosis pre-existed to the femoral neck fracture or if there is an advanced stage ONFH a hemiarthroplasty is indicated. In all cases, careful mobilization and minimal weight bearing should be followed until the BMD value is increased to nearly normal levels.

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