Surgical strategies for high-energy fractures in patients with osteoporosis

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Summary

The most obvious clinical pattern of osteoporosis is represented by the so-called low energy fractures. These are slight trauma bone lesions that would not occur in a subject with normal bone mineral density (BMD). The most frequently affected sites of this type of fracture are the last dorsal and lumbar vertebrae, the proximal femur, humerus, and the distal radius.

These fractures are a challenge for the orthopedic surgeons because they occur on an altered bone, with decreased load resistance, reduced elasticity and decreased ability to absorb mechanical stresses. This physio-pathological pattern results in lower stability of the hardware, lower screws purchase, less resistance to bone-prosthesis interface, lower quality of the healing process.

The problem becomes more complex when high-energy trauma occur in osteoporotic bone with fractures in non-typical locations such as distal femur, tibial plate, tibial malleolus, elbow or peri-phrostetic fractures after Total Knee or Hip Replacement.

The surgical approach to these fractures aims to use devices that assure greater bone-implant stability and a great distribution of stresses by reducing the forces acting on the bone-implant interface.

It is possible to use scaffolds such as bioactive cement and porous coating surfaces to increase the hardware purchase and homologous / autologous transplantation, post-operative pharmacological implementation and growth factors to stimulate potential repair of fractures.

The use of locking plates allows converting the sliding forces, which the traditional plates generated, into compression forces to increase the stability of the system. There are also versatile hardware with dynamic angular stability screws that can be freely oriented in space unlike conventional plates where the direction of the screw is dictated by the placement of the plate.

The philosophy of minimal invasive surgery is well represented by the use of intramedullary nails, which can stabilize the fracture from the inside of the bone marrow. This characteristic ensures a load distribution within the bone especially in meta-diaphysis areas, which are most affected by typical reduction of bone quality of osteoporosis.

In the elderly, the total joint replacement is also indicated in cases of peri-articular fractures in which there is a high risk of bone fragments necrosis. Such fractures can be treated with a prosthetic implant to ensure immediate joint stability and thus allow an early recovery of the range of motion and the function of the affected limb.

Treatment of peri-prosthetic fractures is another important chapter in surgery of traumatic fractures in osteoporosis as we find more and more frequent patients who have a prosthetic implant and who undergo a trauma that causes a peri-implant fracture. In this case, the evaluation of the implant's stability to the bone-prosthesis interface is crucial to decide whether to perform a synthesis with angular stability, nails and/or cerclage wires, or to perform a revision.

In all cases, treatment of traumatic fractures in osteoporosis requires a multidimensional evaluation of the problem, as it is not only the type of fracture and site that can be considered, but also the bone quality by carefully evaluating the patient's functional and metabolic state and its comorbidity. It is a surgery that requires specific implants and devices that must be carried out by experienced hands.

KEY WORDS: osteoporotic; fracture; plate; screws; arthroplasty.

Introduction

Osteoporosis is caused by an imbalance in bone turnover. Age-related increase osteoclastic activity and decrease osteoblastic activity leads to bone mineral loss and structural changes in the bone. Fractures that occurs in osteoporotic bone are characterized by high complication rate related to worse quality of the healing process, reduced elasticity of the bone and lower fixation strength for the fixation devices. We can recognize two patterns of fracture accordingly to the intensity of trauma:

Low-energy fractures typically occurs in osteoporotic bone. These fractures are usually called *"non traumatic fractures"* because of the minor trauma that would not lead fractures in a subject with normal bone mineral density (BMD). They are caused by twisting mechanism or direct load on a weak bone and are consequent to a fall from standing. There is a low grade of soft tissue injury and generally characterized by simple pattern of fracture. Common sites involved are spine, proximal femur, humerus and distal radius.

High-energy fractures are defined as *"traumatic fractures"* caused by major trauma such as direct axial load, bending force, falling from high or motor vehicle crash. The soft tissue envelopes are significantly damaged, sometimes with open fracture and comminution of the fragments. In these cases, fractures may affect atypical sites as the distal femur, tibial plateau, tibial malleolus and elbow or may occur periprosthetic fractures. When traumatic fracture occurs in osteoporotic bone the pattern of fractures associated with soft tissue damage are combined with poor quality of the bone and a reduced healing process. The type of surgical approach to these fractures has the objective of using devices that ensure greater stability at bone-implant interface and a broad distribution of the stresses by reducing the forces acting at the bone-synthesis level (1). In fact, the bone failure, and not the implant breakage, is the primary mode of internal fixation failure in osteoporotic bone. The poor quality of trabecular network would therefore requires adequate fixation elements.

The purpose of this paper is to provide an overview of the main principles of treatment for *traumatic fractures* in osteoporotic bone.

Flaws of traditional implants in osteoporotic bone

Traditional screw design includes cortical and cancellous types. For its peculiar features the cancellous screw are more indicated for metaphyseal and reduced density bone as its increased surface area increases resistance to shear. Instead, the cortical screws are more properly indicated for the diaphysis. Both screw designs obtain fixation strength by generating torque between the bone and threads.

In osteoporotic bone, the ability of the thread-bone interface to produce torque is reduced, and below a threshold bone mineral density (of 0.4 g/cm^3), the changes in screw geometry advantaged by cancellous screws are no longer present (2).

The resistance to pullout of a screw depends not only on the intrinsic characteristics of the screws but also on the bone quality. Compared with trabecular bone, the cortical bone has greater resistance to screw pullout because of its greater mineral density.

Thus, in osteoporotic bone, a smaller diameter cortical screw may be used with a conventional plate than a larger diameter cancellous screw that does not secure cortical purchase (3).

Nevertheless, traditional plates create fixation strength through friction between the bone-implant interface and through compression of fracture fragments. Primary bone healing (endosteal healing) occurs when there is absolute stability (rigid fixation). Compression plating provides an example of a rigid fixation, minimizing strain by decreasing gap motion and prohibiting increase in gap length.

In osteoporotic bone, there is a weak shear interface between the screw and the bone, so that the ability of osteoporotic bone to resist compression is reduced and this disadvantages the typical traditional plate construct. Osteoporotic bone cannot develop sufficient screw torque to generate sufficient normal force to prevent plate and fracture motion. High shear stresses that exceed the strength of cortical bone lead to bone failure in compression or bone absorption and subsequent screw loosening.

Direct anatomical reduction and stable internal fixation of fracture are required for internal fixation using a conventional non-locked plate and screw system, for example Dynamic Compression Plate (DCP). Wide exposure of bone is necessary to allow exact anatomical reduction and stable plate fixation.

In osteoporotic bone, this procedure entails a larger damage to soft tissue and to periosteum, so that an important blood support to the bone is interrupted.

Strengths and weaknesses of locking plates

Locking plates have biomechanical advantages over traditional plate-screw constructs in osteoporotic bone.

These plates achieve stability through a threaded interface between the screw head and plate: in this way, shear forces are converted to compressive forces. Fixation do not rely on frictional forces of bone-implant interface compared to conventional plates and is improved because bone, in particular the osteoporotic bone, has much higher resistance to compressive stress than shear stress (4). These plates are constructs characterized by the absence of motion between its components (5), compared to conventional non-locked plates, where motion occurs between individual components (4). Compression and precise anatomical contouring is not required so that the periosteal blood supply is not damaged. The basic locked internal fixation technique aims at flexible elastic fixation to initiate spontaneous healing and induce of callus formation (6). Secondary bone healing (endochondral ossification), which is characterized by callus formation, occurs when there is relative stability. Locked plates and external fixators can provide such relative stability.

The locking plates allowed the development of minimal invasive percutaneous osteosynthesis (MIPO) (7). The less invasive stabilization system (LISS) is applied via a minimally invasive surgical procedure, lies beneath the deep fascia and muscle, but outside the periosteum, and is anatomically preshaped. It preserves blood circulation because it is inserted through a small incision at the epiphyseal level and is not needed excessive soft-tissue dissection. The fracture must be reduced and held in traction prior application of the plate.

The recent development in the field of variable angle locked plating is the locking compression plate (LCP) that improves fixation using locked compression and gives the option to use the fixator as a reduction tool. The LCP hole can be filled with a conventional cortex screw or a locking head screw (8). In addition, the head of screw has a spherical form, which allows the screw to be fixed at various angles. In this way, they guarantee an increase of holding power, so that even if the screw-bone interface fails, the screw-plate interface remains intact (9).

Multiple angle plates, which aim locking screws in a fracture-specific direction, enable the fixation when minimal distal bone stock exists or in the setting of periprosthetic fracture. Comparison of stability between polyaxial locking and conventional locking plating showed that the polyaxial plate is stiffer in axial and torsional loading and exhibit less irreversible deformation and higher loads to failure (10).

Novel technique is the utilization of both non-locking and locking screws within a single plate construct termed ''hybrid plating''. After reduction of the fracture, non-locking screws are used to compress the plate to bone and help to provide interfragmentary compression. Then, locking screws are placed altering the overall stiffness of the construct.
Little or no callus formation and paucity of callus on the lateral side of the femur, near the locked plate, where interfragmentary motion is most inhibited, generated the concept of far cortical locking (FCL). FCL screws reduce the stiffness of a locked-plate construct and provide parallel interfragmentary motion while retaining construct strength and promoting the symmetrical callus formation. The performance of these constructs relies on a particular FCL screw design that supports screw flexion while providing a controlled motion envelope in the near cortex to prevent flexion of screw shafts beyond their elastic limit.
Dynamic Locking Screws (DLSs) represent another new solution: they consist on a pin-sleeve design, which allows micro-motion within the screw to modulate axial stiffness of locking-screw plate system; screw-bone interface as well as screw-plate interface remains unchanged.
The question of how many screws are needed proximal and distal to the fracture still remains. Generally, in good quality bones, the use of monocortical locking head screws is sufficient; however, at least 3 screws should be inserted on either side of the fracture in each main fragment. In osteoporotic bones, the use of locking head screws is recommended with at least 3 screws in each main fragment, on either side of the fracture, of which at least 1 must be inserted bicortically. It is important to avoid stress concentration at the fracture site, while 2- or 3-plate holes in fracture zone without screws lead to stress distribution (6).
Locking plates are the fixation method of choice, for osteoporotic diaphyseal and metaphyseal fractures, for bridging of severely comminuted fractures to minimize soft-tissue damage and for the plating of fractures where a compression plate may not be placed on the tension side of fracture.

Internal fixation with intramedullary nail

The philosophy of minimal invasive surgery is well represented by the use of intramedullary nails, which allow to stabilize the fracture from the inside of the medullary canal so as to ensure a load distribution within the bone, especially in areas most affected by the meta-diaphyseal reduction of bone quality typical of osteoporosis.
Nails, which are a load-sharing device centrally located within the bone, theoretically provide more efficient load transfer than does a sliding hip screw.
Intramedullary nailing is a fixation method superior to plates or external fixation, because the location of the rod in the intramedullary canal virtually guarantees proper axial alignment; also, rotational alignment can be ensured with interlocking screws.
With intramedullary nails, it is possible to minimize soft-tissue insult and fracture devitalization, so that the periosteal and endosteal blood supply are not damaged. If it is necessary to ream the medullary canal, the internal cortical blood supply could be damaged, but animal experiments has shown how this process is reversible within 8-12 weeks (11).
The shorter lever arm of this device can be expected to decrease tensile strain on the implant, thereby decreasing the risk of implant failure and providing a relative stability with secondary bone healing and callus formation.
The intramedullary location limits the amount of sliding, therefore limb shortening and deformity that can occur; the fracture can settle until the proximal fragment abuts against the nail. Placement of screws in multiple planes, the addition of bone cement and locked interlock bolts have all shown increased stability in metaphyseal segments and with osteoporotic bone (12, 13).
The widened canal of osteoporotic bone accepts large diameter nails at the cost of increased construct rigidity. Excessive rigid nails show decreasing callus formation leading to concerns over non-union (14). A balance must be reached between canal fitting nails and construct rigidity. Adjuncts such as blocking screws may assist in both reduction and in nail stability while allowing a smaller, less rigid nail to be used.
However, the high stiffness and the low micromotion across the fracture gap with axial compression allow early rehabilitation and early weight bearing.

Augmentation and scaffolds

Many options, not considering pharmacological agents (15), has been described to increase the strength of device fixation, to fill bony defects and increase the potential healing of fractures.
The biology of bone grafts and their substitutes is appreciated from an understanding of the bone formation processes of osteogenesis, Osteoinduction and Osteoconduction.
Graft osteogenesis: the cellular elements within a donor graft, which survive transplantation and synthesize new bone at the recipient site.
Graft osteoinduction: new bone realized through the active recruitment of host mesenchymal stem cells from the surrounding tissue, which differentiate into bone-forming osteoblasts. This process is facilitated by the presence of growth factors within the graft, principally bone morphogenic proteins (BMPs).
Graft osteoconduction: the facilitation of blood-vessel incursion and new-bone formation into a defined passive trellis structure.
All bone graft and bone-graft-substitute materials can be described through these processes.

Autologous cancellous bone
Augmentation of osteoporotic fractures with osteoconductive bone grafts both maintains reduction of the fracture and also provides a scaffold for ingrowth of new bone near the interface between host bone and the fixation device (16).
Cancellous bone from iliac crest is the current "gold standard" treatment in the management of bone loss. The use of autografts diminishes the risk of infectious disease transmission, whereas osteoconductive, osteoinductive, and osteogenic properties of the graft are optimal. Moreover, there is no immune response after implantation, enhancing its ability to incorporate into its new site.
However, there are major drawbacks to the use of autologous bone, especially in elderly such as reduction of osteogenic activities, limited availability, hematoma formation, increased operative time and bleeding, chronic donor site pain (17).

Structural and morselized bone allografts

Structural and morselized forms are available and prepared as either fresh-frozen or freeze-dried. These grafts provide a structural framework or scaffold for host tissue to grow, hence making allograft osteoconductive. Conversely, its osteoinductive properties are mediocre at best. Upon implantation, the host is expected to experience an intricate immune response (18, 19).
Freezing or freeze-drying the allograft is crucial in minimizing this reaction; however, the fundamental properties of the material may be altered.
Although the risk of disease transmission through implantation of allograft is rare, its existence is not inconsequential. Sterilization techniques such as exposure to gamma irradiation and ethylene oxide significantly decrease the risk of transmitting infection but subsequently decrease the osteoinductive properties of the graft.
The most apparent limitation of cadaveric allograft is its lack of osteoinductive capabilities. Demineralized bone matrix is a derivative of allograft bone and is prepared by pulverization of allogenic bone to a consistent size, followed by mild acid extraction of the mineralized phase of bone (20); the result of this process is a composite of noncollagenous proteins, growth factors, and collagen. Demineralized bone matrix is osteoconductive but does not provide structural support. Osteoinductive capabilities are increased because of the released growth factors during the demineralization process (19). Rinsing these trabecular allografts may enhance graft incorporation by washing out immunogenic factors present in blood, marrow and fat. However, it has been proposed that impaction of the graft releases biologically active factors, which can provide sufficient activity to stimulate new bone formation, so that it seems to be better rinsing before impaction to enhance bone allograft incorporation (21).
When preparing demineralized bone matrix for implantation, it is usually mixed with bone marrow, increasing possible osteogenic factors and pluripotential cells. It can also be used as an autogenous bone graft expander (22).

Allograft

Another form of osteoporotic fracture fixation augmentation is the use of allograft fibulas. Allograft fibulas have been used as reduction tools as well as medial calcar support in comminuted proximal humerus fractures (23, 24).
The intramedullary strut increases load to failure when used with a lateral locked plate both by cortical substitution and by supporting the head segment from a central location (25). Intramedullary placement of an allograft may also aid in screw purchase similar to that seen with intramedullary wire placement in osteoporotic fibula fractures (26).

Injectable cements

Calcium Phosphate Cements (CPCs), offer the advantages of good adhesion to bone, remodelling and consequent replacement with new bone (27) and are often used to fill voids caused by severe osteoporosis or comminution of the host bone (28). While bone cement is able to increase surface area through interdigitations in porous bone, it may also cause thermal bone necrosis at the screw bone interface causing loosening. Bone cements may inhibit bone healing as a mechanical block to bone bridging when aberrantly placed within a fracture site and their use is cautioned against (29).

Porous coatings

Screw coatings such as hydroxyapatite and bisphosphonates have been used to increase the purchase of the screw within osteoporotic bone by direct bone growth on the screw or by increasing the local quality of bone respectively (30-32).
Porous metal has been introduced to obtain biological fixation and improve longevity of orthopaedic implants. The new generation of porous metal has intriguing characteristics that allows bone healing and high osteointegration of the metallic implants (33).

Total joint replacement for peri-articular fractures

Poor bone quality, comminution and displacement of the fragments often results in many technical problems and obtain adequate fixation is a challenge. High complication rates have been reported after internal fixation in elderly patients with osteoporotic bone, severe comminution and poor soft-tissue quality. Primary total arthroplasty has been advocated as a treatment options in patients with periarticular fractures combined with comminution and osteoporosis, with improved clinical results compared with internal fixation (34, 35).
THA (Total Hip Arthroplasty) and TKA (Total Knee Arthroplasty) in osteoporotic bone allow early mobilisation and immediate full weight bearing avoiding complications related to anatomic reduction of comminuted fragments and timing of fracture healing.
Femoral neck fracture even if typically are considered non-traumatic fractures could also be caused by high-energy trauma. Treatment especially for those with comminution or displacement of the femoral head is hip replacement. The use of dual-mobility cup systems for this procedure has been proved helpful in elderly to reduce the dislocation rate. With the dual-mobility cup, the prosthetic head is mobile in a retentive polyethylene (PE), which is free to move in a metal-backed cup. There is one motion that occurs between the inner femoral head and the inner concave surface of the PE bearing, and a secondary motion that occurs between the PE bearing and the acetabular cup. Advantages of this system are greater ROM and increased stability of the implant (Figure 1) (36, 37).
Periarticular knee fractures also can be managed with total knee arthroplasty especially when fracture is associated to osteoarthritic degeneration of the joint. Many system allow managing the bony defect with wedges, sleeves or cements and stems also increase implant stability.
Total replacement of the joint should be used for that fractures in which osteosynthesis fixation can be compromised both in conventional sites as proximal humerus and wrist or in non-conventional sites as elbow.
In patients older than 65 years, presenting a comminuted fracture on osteoporotic bone with limited functional requests, total elbow arthroplasty may be considered.
The indications for wrist prosthesis were fractures with metaphyseal comminution, significant radial shortening, articular comminution (C2 distal radius fractures according to the AO classification) in patients older than 70 years without distal ulna fractures (except the ulnar styloid process) (38).
In elderly patients with poor bone stock, humerus head dislocation and severely displaced head fragments, either hemi-arthroplasty or reverse total shoulder arthroplasty is a good alternative surgical treatment, the last one in particular when there is a significant rotator cuff tear.

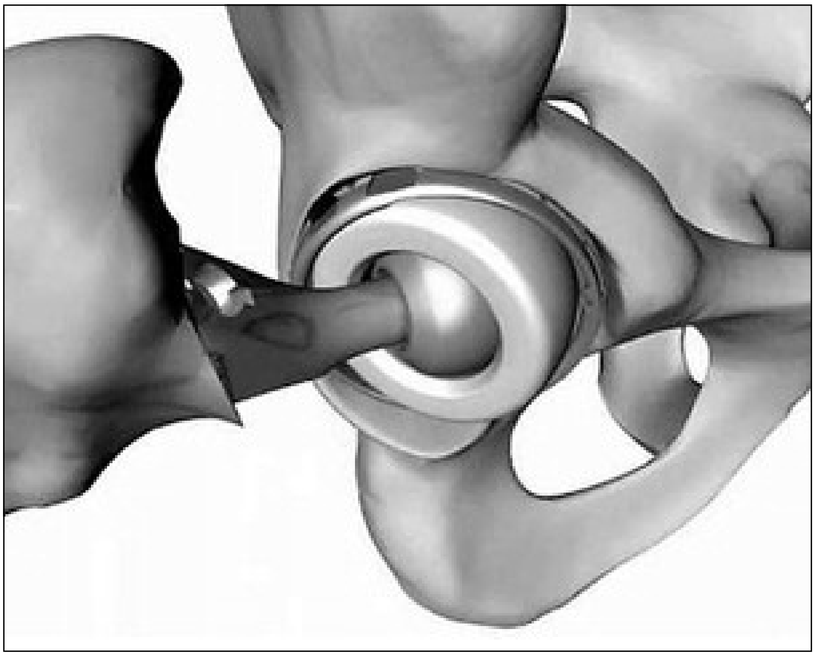

Figure 1 - Dual-Mobility Cup System in Total Hip Arthroplasty.

Conclusions

In the osteoporotic patient, traumatic fractures have a pattern and a various different distribution compared to low energy fractures.
Although the basic principles are analogous, often it is necessary to resort to synthetic and biological augments, dedicated plates and screw, intramedullary nailing and to wedges and/or sleeves when bone stock loss is relevant.
Moreover, when not all these solutions are enough, prosthetic replacements may be considered.

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