Principles of fixation of osteoporotic fractures

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Despite advances in the prevention and treatment of osteoporotic fractures, their prevalence continues to increase. Their operative treatment remains a challenge for the surgeon, often with unpredictable outcomes. This review highlights the current aspects of management of these fractures and focuses on advances in implant design and surgical technique.

Osteoporosis is a skeletal disorder characterised by compromised bone strength, predisposing to an increased risk of fracture. In the clinical setting, it can be defined as a reduction in bone mass of $>2.5\text{SD}$ below the mean for a young adult. More than 40% of women and 14% of men over the age of 50 years will experience fractures related to osteoporosis. Globally, approximately 200 million people are at risk of sustaining an osteoporotic fracture each year. It is expected that osteoporosis will become epidemic in the years to come as a result of the increasing number of elderly people. By 2012, 25% of the European population will be over the age of 65 years and by 2050, 52 million people will be over this age in the United States.

The most frequent osteoporotic fractures seen in men arise in the ribs, spine, and wrist, whereas in women the common fracture sites include the wrist, spine, ribs, humerus and femur. In the elderly, the rising incidence of proximal fracture of the femur represents the most important socio-economic impact of osteoporosis. In 2000, there were approximately 424 000 hip fractures worldwide in men and 1 098 000 in women. Based upon altering demographics and the increase in life expectancy, it is estimated that by 2025 there will be an increase of 89% in men, resulting in 800 000 hip fractures per year, and in women the numbers will rise by 69% to 1.8 million.

Osteoporosis is characterised by thinner bone. Endosteal diaphyseal resorption and medullary expansion are common in both men and women. The changes in diameter of the inner and outer cortices affect the bending and torsional characteristics of the entire bone and predispose to low-energy fractures, which often have a complex pattern. At a tissue level, there is a decrease in the cancellous bone mineral density. There is also a decrease in the density of cortical bone, because of an increase in porosity, which can affect the holding capacity of screws.

The healing of a fracture in osteoporotic bone passes through the normal stages and concludes with union of the fracture although the healing process is prolonged. There is evidence of this from animal models. Namkung-Matthail et al showed a 40% reduction of callus in the cross-sectional area and a 23% reduction in bone mineral density in the healing femur of an osteoporotic rat model (ovariectomy and low calcium diet). Similar results demonstrating that healing took longer in older rats, and that both stiffness and strength remained below the values of controls, were found by Meyer et al. Clinically, although delay in fracture healing is not always obvious, the decreased healing capacity in osteoporosis is reflected in a dramatic increase in the rate of failure of implant fixation. There are several possible explanations for this effect. There might be fewer mesenchymal stem cells in osteoporotic individuals, which have a lower proliferative response. This may explain the age-related decrease in the number of osteoblasts. Mesenchymal stem cells in post-menopausal women differ from those in the premenopausal by having a lower rate of growth and a deficiency in their ability to differentiate along the osteogenic lineage. Finally, bone cells from osteoporotic patients may have an impaired long-term response to mechanical stress.
The stabilisation of osteoporotic fractures can, therefore, be problematic, despite optimal surgical techniques. The purpose of this review is to highlight the current principles of fixation for osteoporotic fractures.

**Technical aspects**

The major technical problem facing the surgeon is the difficulty in obtaining secure fixation of an implant to osteoporotic bone. There is less cortical and cancellous bone for the screw threads to gain purchase, so that the pull-out strength of implants is significantly reduced. Bone mineral density correlates linearly with the holding power of screws.\(^{20,21}\) The load transmitted at the bone-implant interface can often exceed the reduced strain tolerance of osteoporotic bone. This may result in microfracture, resorption of the bone, and loosening of the implant, with secondary failure of fixation.\(^{22,23}\) Consequently, the common mode of failure of internal fixation in osteoporotic bone is bone failure rather than implant breakage. Because of this, the operative treatment of metaphyseal fractures in the elderly is associated with an increased rate of complications; non-union and implant failure occur in 2% to 10% of fractures, malunion in 4% to 40% and re-operation in 3% to 23%.\(^{24,26}\)

This high rate of complications has encouraged extensive research into the development of implants which can improve the bone-implant interface by preventing high stress and distributing the forces transmitted to bone in a load-sharing, rather than load-bearing way.

The general principles of fracture management in osteoporotic bone require some changes in surgical technique in order to decrease the risk of failure at the bone-implant interface. These include the use of relative stability techniques such as intramedullary nails, bone impaction, buttress fixation, fixed-angle devices, bone augmentation and joint replacement. Techniques of internal fixation which aim to provide absolute stability with lag screws are usually inappropriate in osteoporotic bone.\(^{20}\) Relative stability techniques are the most efficient at reducing strain at the bone-implant interface, as the implant is within the load-bearing axis of the bone.

Buttress-plate fixation of metaphyseal fractures is effective in osteoporotic bone as it avoids high strain at a single screw while the implant provides a large contact area at the bone-implant interface, again reducing strain.\(^{27}\)

Fixed-angle devices, such as the angled blade plate, are very useful as they resist angular deformation and torsion, and the strain is reduced because the blade has a large surface area.\(^{28}\) Initial success with fixed-angle implants such as the blade plate\(^{29}\) has led to the development of screws which are rigidly fixed to the plate. This was first achieved by adding Schuhli nuts (Synthes, Paoli, Pennsylvania) to standard plates and, more recently, with threaded holes incorporated directly into the plate, the so-called locking compression plates.\(^{30,31}\) Plates with locking-head screws also produce a fixed-angle device and have similar mechanical properties. The holding power of an implant can be increased further by having locked screws at multiple fixed angles.\(^{32}\) An early vision of this was the point contact fixator, which proved useful in fractures of the forearm.\(^{33}\)

The main advantage of the locking-plate device is the mechanical couple between the screw head and the plate (fixed-angle device) so that even if the screw-bone interface fails, the screw-plate interface remains intact. Complete failure of fixation is still possible, and is seen in very severe osteoporosis, but all screws on one side of the fracture fixation must fail simultaneously. Therefore, implants such as the locking compression plate and the less invasive stabilisation system have significant advantages in osteoporotic bone.\(^{27}\) Comparison between conventional and locking plates have been conducted in distal\(^{34}\) and diaphyseal fractures of the humerus\(^{35}\) and were shown to be better suited to providing stable and reliable fixation. A review of the available literature in the field of plate osteosynthesis\(^{36}\) came to the same conclusion. Similar developments to include the principle of angular stability in intramedullary nails, are now underway.\(^{37,38}\) The treatment of unstable fractures of the proximal humerus using these nails has demonstrated that a stable osteosynthesis is achievable in very old patients.\(^{39}\)

Bone impaction is important as it reduces the risk of implant failure before bony union has occurred. In many cases, for example the valgus impacted fracture of the femoral neck, impaction is created by the injury itself. Controlled impaction can be achieved by tensioning internal fixation devices such as the dynamic hip screw, which allows controlled impaction of the fracture while preventing penetration of the joint by the screw.\(^{40}\)

Bone augmentation can be achieved by using bone autograft or allograft, bone cement or bone substitutes.\(^{41-43}\) Improvements in screw fixation using cement have been reported by several authors.\(^{44-51}\) Reynders and Label\(^{44}\) used a cannulated screw with side openings in order to inject polymethylmethacrylate (PMMA) around the screws and thereby enhance their purchase in fractures of the humerus, femur and tibia. Pull-out forces measured in human femoral condyles were significantly increased. A similar screw was used by McKoy and An\(^ {45}\) and was shown to improve pull-out forces in lumbar vertebral bodies by 278% when compared with screws secured with PMMA which had been injected before insertion of the screw. A similar principle was applied to a dynamic hip screw by Kramer et al\(^ {46}\) and was shown to improve fixation, although local cement application through the implant was limited. Eriksson et al\(^ {47}\) compared conventional PMMA with Norian SRS (Synthes, West Chester, Pennsylvania) calcium phosphate cement in laboratory tests and found PMMA to have superior torque and pull-out strength, irrespective of the type of implant. The advantage of Norian to remodel into bone was not taken into account. Other investigations have reported similar results.\(^ {48-51}\)

Resorbable polymers could also be used to provide the additional stability needed in osteoporotic fractures until
healing has occurred. Mainil-Varlet et al showed that an intramedullary augmentation device made of poly(l-lactide) provided the same resistance against pull-out as PMMA cement.

Joint replacement is another option for osteoporotic patients with articular fractures, and some metaphyseal fractures, where internal fixation is inappropriate or the patient has pre-existing arthritis. In general, these patients will be in the same age group (over 65 years of age) as those who might receive a joint replacement for arthritis, such as those with displaced intracapsular fractures of the proximal femur or proximal humerus, and fractures of the distal humerus.

Biological processes which enhance the healing potential of osteoporotic fractures should also be considered as an adjunct to surgery, particularly the influence of coating of the implant on the bone-implant interface. In a comparative study of patients with an osteoporotic fracture of the wrist who received hydroxyapatite(HA)-coated versus uncoated external fixator pins, the patients with HA-coated pins had better pin fixation and fewer pin-track infections. Similar results were obtained by Moroni et al in elderly patients with trochanteric fractures who had been treated with HA-coated screws to secure a four-hole dynamic hip screw. Such coatings can also be used as drug delivery systems, such as for bisphosphonates. Tengvall et al have shown that bisphosphonates engraved on stainless steel screws showed a 28% higher pull-out force after being implanted for two weeks in rat tibiae. Implant surfaces can also be used to deliver growth factors, such as bone morphogenetic protein (BMP-2, BMP-7), transforming growth factor (TGF-β) or fibroblast growth factor (FGF) locally to influence bone formation and perhaps improve implant fixation. However, their benefit in osteoporosis remains to be seen. Another biotechnological approach would be to employ bone tissue-engineering using a suitable scaffold material and adult mesenchymal stem cells. Significant research will be necessary to develop this area into routine clinical practice. Finally, gene transfer techniques can deliver authentically-processed gene products to precise anatomical locations at therapeutic levels for sustained periods. However, the selection of the gene or gene combinations, and safety issues, are some of the factors which need to be addressed before a clinical application can be devised.

**Surgical treatment**

The treatment of fractures is determined by three important factors; the soft tissues, the fracture pattern, and the patient. In the elderly, each of these factors may present particular problems. The soft tissues and skin may be thin because of atrophy or malnutrition thereby predisposing to degloving injuries. Arterial disease may result in ischaemic changes and poor healing, while venous hypertension produces oedema, ulcers and chronic skin changes. Fracture patterns are often complex because of the altered mechan-
ical properties of bone, despite the low-energy nature of the injury. Patient factors are often complex in the elderly, because the majority of patients have medical comorbidities which require careful assessment.

In the clinical setting, common osteoporotic fractures which may give rise to difficulties with treatment include fractures of the proximal humerus, distal radius, proximal and distal femur, and spine.

Fractures of the proximal humerus remain a difficult problem. They are often complex with associated damage to the muscles of the rotator cuff leading to poor shoulder function. In three- or four-part fractures, there is often insufficient bone to achieve a good purchase with internal fixation devices. For this reason intramedullary devices have been developed, which are located more medially, have a shorter lever arm, preserve the blood supply of the periosteum and soft tissues, and are inserted with a minimally-invasive technique. Their central location provides a uniform load distribution. However, if there is an unstable or comminuted lateral metaphyseal fracture, and particularly if the starting point extends into the greater tuberosity, failure of fixation or fracture displacement may occur. It was these concerns which led to the development of the proximal humeral locking compression plate (Synthes, Oberdorf, Germany) (Fig. 1). This device offers the advantage of locking head-screws which enter the humeral head at various angles in order to maximise purchase and create a fixed-angle device. Additional holes in the plate allow tension-band fixation of the rotator cuff while the anatomical design of the implant allows easier application of the plate and minimises subacromial impingement. Bjorkenheim, Pajarinen and Savolainen treated 72 patients with a locking compression plate and reported good results. They concluded that this method of stabilisation was safe and could be recommended for the treatment of fractures of the proximal humerus in patients with poor bone stock.

For fractures of the distal radius, although there have been a number of small randomised trials, the best fixation technique in the elderly remains unknown. Available techniques include closed reduction and Kirschner-wire fixation, intrafocal pinning (Kapandji technique), external fixation with bridging or non-bridging fixators, and internal fixation using dorsal or volar plates. Bone graft or calcium phosphate cements have been used alone (with a plaster cast) or to augment other fixation techniques. Fractures with dorsal angulation often have comminution and impaction of bone on the dorsal aspect of the radius. In this situation, the ideal mechanical fixation is a dorsal buttress plate. This allows good reduction, but impingement of the plate on the extensor tendons may result in poor function. The development of locking compression plates offers the possibility of volar plate fixation for those fractures with dorsal angulation and comminution (Fig. 2). The volar approach minimises soft-tissue problems while the fixed-angle screws maintain radial length without the need for a buttress.

Fractures of the hip have a high morbidity and mortality in the elderly with up to 10% of patients dying within 30 days of surgery and 30% dying within one year. Approximately 60% of fractures of the hip in the elderly are intra-capsular. Undisplaced or impacted fractures are normally managed by internal fixation using lag screws or a dynamic hip screw while the management of displaced fractures is more controversial. The basic choice is between prosthetic replacement with a hemiarthroplasty.
or total hip replacement, or reduction and internal fixation. Many factors will influence decision-making. In general, age is not important but pre-injury mobility, residential status and cognitive function all affect prognosis and are key factors. Extracapsular fractures require reduction and internal fixation. Although a major technical problem is secondary fracture impaction, a dynamic hip screw allows this to occur along the axis of its screw. Accurate placement of the screw in the femoral head is best measured by the tip-apex distance and determines the performance of the device, particularly in osteoporotic bone. There are also other options for the unstable pertrochanteric fracture, including the intramedullary hip screws. Recently, Moroni et al have reported that selective osteoporotic pertrochanteric fractures can be successfully treated by external fixation.

For osteoporotic fractures of the distal femur, good results have been reported with the application of the less invasive stabilisation system locking device, with or without augmentation.

For fractures of the spine, which are the most common osteoporotic fractures, recent advances include vertebroplasty and kyphoplasty. Vertebroplasty uses the injection of bone cement directly into the vertebral body through a pedicular or extrapedicular approach under fluoroscopic control. There is no reduction of the kyphotic deformity nor any restoration of vertebral height, the aim being to prevent further collapse and relieve pain. Kyphoplasty uses a balloon tamp which is introduced into the vertebral body and inflated in order to reduce the fracture and restore vertebral height. The cavity is then injected with low-pressure cement. Both vertebroplasty and kyphoplasty clearly lead to pain relief. However, their value remains to be determined by prospective randomised trials.

Significant developments have taken place in order to address the difficulties which surgeons have encountered over the years in the stabilisation of osteoporotic fractures. These can be summarised as being technique-related (bone impaction, buttress fixation, bone augmentation, lever-arm modification) and implant-related (fixed-angle devices, locking plates, coating of implants, joint replacement implants). Figure 3 summarises these current principles in the management of osteoporotic fractures.
References


