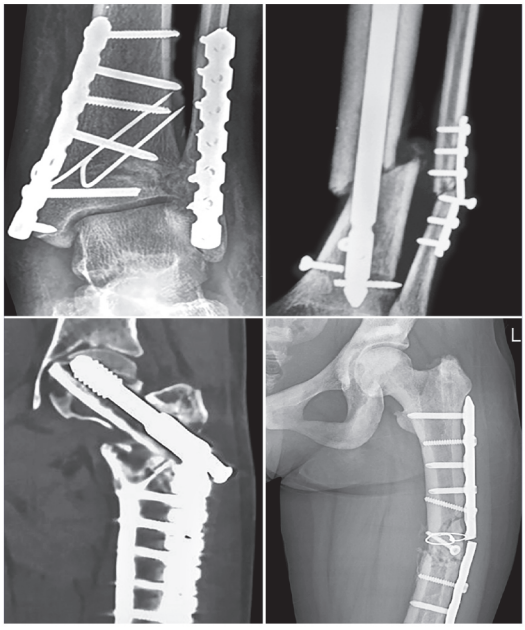
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6

Master Series Monographs

Failed Fracture Fixation

Volume 2: Lower Limb



Editor-in-Chief
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Sachin Bhonsale

JAYPEE

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2 Minimizing Failure of Fracture Fixation in Osteoporotic Bones

DD Tanna, Harshad Argekar, Gautam Zaveri

Introduction

Fractures in brittle bone weakened by osteoporosis, form a significant chunk of the practice of most orthopedic surgeons. Osteoporosis in older individuals is secondary to age-related degradation of bone. Chronic illnesses, medications used to treat various medical issues, and lack of exercise may also contribute to progressive weakening of bones. For cortical bone, stiffness decreases by 1–2% per decade, and strength decreases by 2–5% per decade.[1] The energy required to fracture a bone may decrease by up to 10% per decade beyond the age of 35 years.[2] By age of 80 years, the strength of the bone from the proximal femur is reduced by > 50% from its strength at young age.[3] Even more pronounced is the loss of mechanical strength at the spine where the strength reduction has been reported to amount to up to 70%.[4]

In elderly patients, successful treatment of the fracture with rapid recovery of mobility is essential for survival and wellbeing. Successful healing of the fracture requires a mechanically stable internal fixation. However, getting optimal implant fixation in osteoporosis is challenging, and failure of fixation is a frequent occurrence **(Fig 1)**. The holding force of screws decreases by 1000N (50%) for 1 mm loss of cortical thickness.[5] Fixation failure is more commonly due to bone failure, rather than implant breakage. Understanding the biomechanics of fixation will help minimize these failures and provide improved outcomes for these patients.

Challenges Faced in the Elderly

The treatment of elderly patients with fractures is quite challenging. Not only does osteoporotic bone have a higher propensity to fracture, but it reduces bone density and increases brittleness which results in fractures with more comminution and complex fracture patterns compared to healthy bone.[6] Fracture fixation in osteoporotic bone is fraught with complications such as implant loosening, implant cut-out, and peri-implant fractures.

Furthermore, elderly people have a decreased capacity to manage functional limitations. They often have issues with maintaining balance and coordination.[7] They are unable to cooperate with limitations in weight bearing, and keeping them off their feet increases muscle atrophy, bone

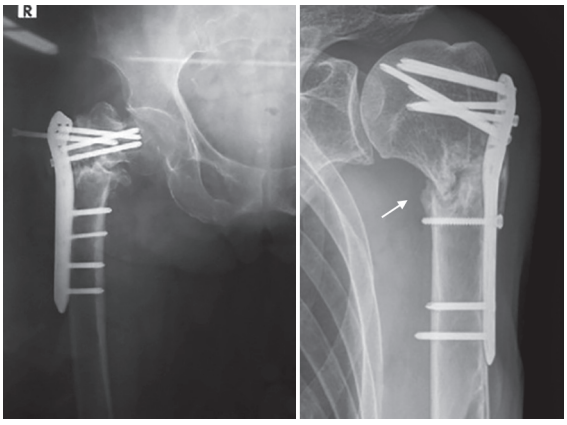


Fig 1: Plain radiographs of failed fracture fixation with varus collapse and nonunion of the fracture.

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loss, and loss of confidence, making subsequent rehabilitation difficult. Hence, fracture fixation must be robust, so as to permit immediate postoperative weight bearing.

Finally, most elderly patients have associated comorbidities, with many of them being on long-term medications. This makes elderly individuals much more vulnerable to post-traumatic and perioperative complications and challenging candidates for rehabilitation.

Requirements for Fracture Fixation in the Elderly[8]

- Surgeries need to be quick and minimally invasive in order to limit perioperative morbidity and complications.
- The fractures need to be fixed so as to provide maximal stability in order to withstand immediate full weight-bearing.
- Implants need to withstand loosening or be otherwise reinforced or augmented to prevent failure.

Principles of Fixation in Osteoporotic Bone

In their paper on "Failure of Fracture Fixation in Osteoporotic Bone," Christian von Rüden et al, have listed some surgical principles which enhance fracture fixation in osteoporotic bone.[9]

Primary Stability

Primary stability must be obtained using a strong but load sharing implant-bone construct. Internal fixation devices that allow maximum contact area between implant and bone, minimize stress at the bone-implant interface. Preferred implants include long plates, nails with many locking options, or plates with a larger surface area providing more possibilities for screw placement. Plates with a larger contact area reduce compressional stress on bone. Screws with a smaller diameter generate less strain within both cortical and trabecular bone, and also provide flexibility that allows wider load distribution.

Secondary Stability

Secondary stability can be provided only after adequate primary stability is achieved. Additional stability provides a mechanical environment which promotes bone healing and limits risk of delayed union, nonunion, and implant failure. However, care must be taken to prevent concentration of strain and excessive strain, as bone fatigues and fails at regions of excessive strain. Hence, implants which distribute the strain over a larger area by large surfaces or by more screws or bolts may prevent bone from early fatigue. Additional stability is provided by using additional implants such as cerclage wires, cables, plates, and external devices which provide antiglide mechanism or antirotation property that can prevent secondary loads on implants. For example, additional antirotation screws in dynamic hip screw systems, supporting plates for femoral neck screws, and in certain situations the augmentation of screws with bone cement.

Correct Alignment and Accurate Fracture Reposition

Optimum load sharing between the implant and host bone across the fracture site and across adjacent joints, requires restoration of the anatomic continuity of the weight bearing column with accurate repositioning of fracture fragments, and realignment of the load bearing axis. Compression across the fracture site improves primary and secondary stability by enhancing load sharing between bone and implant. In the absence of an adequate weight bearing column, the implant has to bear excessive bending

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moments, which may result in failure of bone or implant. In osteoporosis, the bone is more likely to give up than the implant, resulting in collapse at the fracture site, implant loosening and cutout. For example, anatomic reduction and restoration of anteromedial continuity has been found to be crucial to healing of complex intertrochanteric fractures in the elderly. In the absence of cortical continuity across the weight bearing column because of comminution, alternatives include strut bone grafts, use of bone substitutes, and bone cement to fill the void and offer compressive stability.

Adequate Mechanical Environment

Healing of a fracture relies on synchronized action of biological factors and the mechanical environment.

Absolute stability conferred by stable constructs allows primary fracture healing through endosteal bone formation, without formation of periosteal callus. This requires bone-to-bone apposition through accurate fracture reduction and compression across the fracture site. This mechanical environment is recommended when dealing with intraarticular fractures, that require rigid immobilization of the articular fragments to allow bone healing and permit early joint mobilization.

Relative stability conferred by more elastic constructs allows interfragmentary motion that stimulates formation of periosteal callus and results in secondary fracture healing. This type of fixation is preferred for metaphyseal and diaphyseal fractures. In the central diaphysis, closed reamed intramedullary nailing with maximum locking both proximally and distally is the construct of choice. In the metaphysis, locking plates with a long span length and a large working length provides elastic fixation that stimulates periosteal bone formation. Titanium offers superior elasticity as compared to stainless steel.

Methods of Augmenting Stability[10]

Dual Plating

Application of two plates at 90° or 180° to each other, is a technique that is frequently used to enhance stability in rotation and bending at the fracture site. Typically, the second plate should be shorter than the primary fixation to prevent stress concentration at the ends of the plate **(Fig 2)**. The disadvantage of dual plating is the need for extensive exposure or dual exposure, both of which may compromise vascularity. Additionally, multiple screw holes in different directions may complicate revision fixation, if necessary. For primary fixation in osteoporotic bone, the use of dual plating is commonly seen in distal humerus, proximal tibia, and distal tibia fractures. It is often used for nonunions with failed fracture fixation.

Cement Augmentation

Polymethyl methacrylate bone cement has been used to enhance fixation of screws within both cortical and cancellous bone. Polymethylmethacrylate (PMMA) increases



Fig 2: Plain radiographs of orthogonal plating done for failed fixation of a distal femur fracture.

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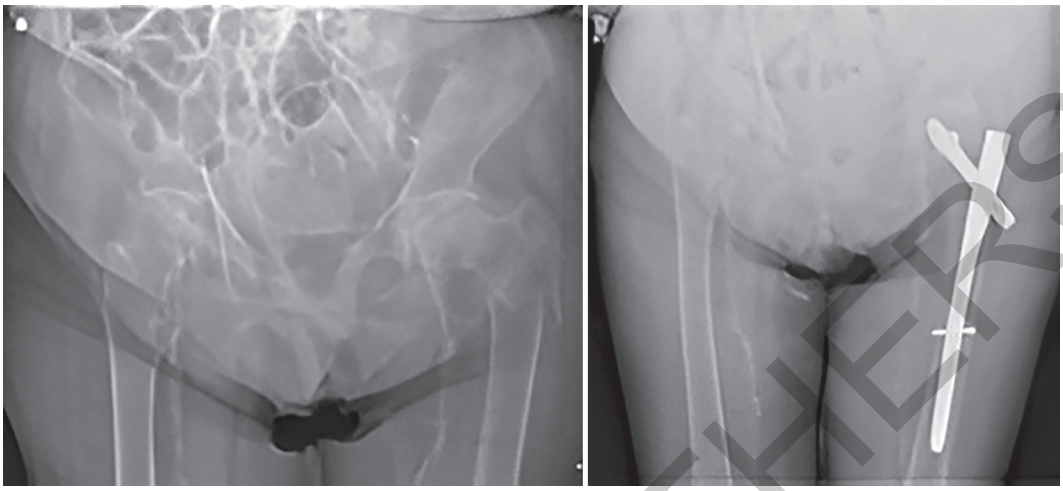


Fig 3: Plain radiographs of a proximal femur fracture in an 88-year-old patient, fixed with proximal femoral nail (PFN) and hip screw augmented with bone cement.

the pullout strength of screws **(Fig 3)**. PMMA-augmented pedicle screws in cadaveric spines have a 1.2–2.1 fold increase in pullout strength when compared to solid screws without cement.[11] Historically, the screw tract was first prepared, the cement was injected and then the screws were quickly inserted before setting of the cement. Newer implants have fenestrations at the tip of the screw, permitting cement to be inserted after the screw has been inserted. For example, PMMA cement has been used to augment fixation of screws within the femoral head-neck region when fixing intertrochanteric fractures in the elderly. Cement has also been used to fill bone voids. By filling the bone defect, it augments stability of the bone-implant construct, permitting early weight bearing mobilization. For example, it has been used to fill metaphyseal defects after elevation of compressed articular fragments in the proximal tibia.

However, PMMA is simply a filler which does not get incorporated into the host bone nor does it allow for remodeling. Additionally, PMMA injection carries risk of leakage into the vascular system, resulting in cement embolism. In the spine, where PMMA cement is commonly used for vertebroplasty, cement leakage into the spinal canal can result in spinal cord or nerve root compression. In case of a surgical site infection, removal of cement is extremely difficult. The heat generated during cement curing can result in necrosis of surrounding bone. Calcium sulfate cement is a biologically inert, moldable, and osteoinductive material that provides a scaffold for osteoblasts. It predictably dissolves in 6–8 weeks. It is utilized as a carrier of bone growth or antibiotic compounds.[12]

Bone Substitutes

Alternative cements/fillers such as calcium phosphate, calcium sulfate, and bioactive glasses are more biocompatible, sometimes resorbable, but mechanical strength may lag behind PMMA under certain loads. Allograft bone has also been used as a scaffold to supplement autogenous bone for large defects. Bone morphogenetic protein (BMP7) has also been used to stimulate bone formation, although it has the disadvantage of resulting in florid heterotopic bone formation.

Locked Plates

Locked plates use screws with threads within the head portion, that lock with the threads within the screw hole. The construct then becomes a fixed

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angle implant with multiple points of fixation. The locked screw does not toggle within the bone on loading and hence does not cut through the bone on cyclical loading. Locking screws have a thicker core diameter which increases bending stiffness. Locked plates are not compressed onto the bone surface and hence the bone around the screws experiences very little preload. Transfer of load across the fracture site occurs from the bone to the plate through the heads of the locking screws. The load transfer from the bone to the screw is distributed along the length of the screw wherever the screw is in contact with bone.[9]

Locked plates offer increased fatigue strength and increased ultimate load to failure compared to conventional plates.[13] They are extremely useful for periarticular fractures, comminuted fractures, and in osteoporotic bone **(Fig 4)**. However, there is no particular advantage to using locked plates in good quality bone. Older plates used to come with screws that could be inserted at fixed angles. The current generation of locked plates allow variable angle screw placement, which offers fracture specific fixation. However, the variable angle screwheads are bulkier and possess less strength and stability.

Disadvantages of locked plates include intra-articular placement of screws and incomplete fracture fixation due to fixed angle constructs, coronal plane peri-implant fractures, delayed union and nonunion due to excessive implant stiffness, and fractures through the multiple screws.[14]

Total Joint Arthroplasty

For patients with extremely weak bone, periprosthetic fractures and failed prior fixation, surgical fixation is often fraught with repeated failures and poor clinical outcomes. In selected patients, the entire pathological segment or fractured region is discarded or bypassed by performing a joint replacement surgery **(Fig 5)**. Proximal and



Fig 4: Precontoured locking plate for the distal radius.

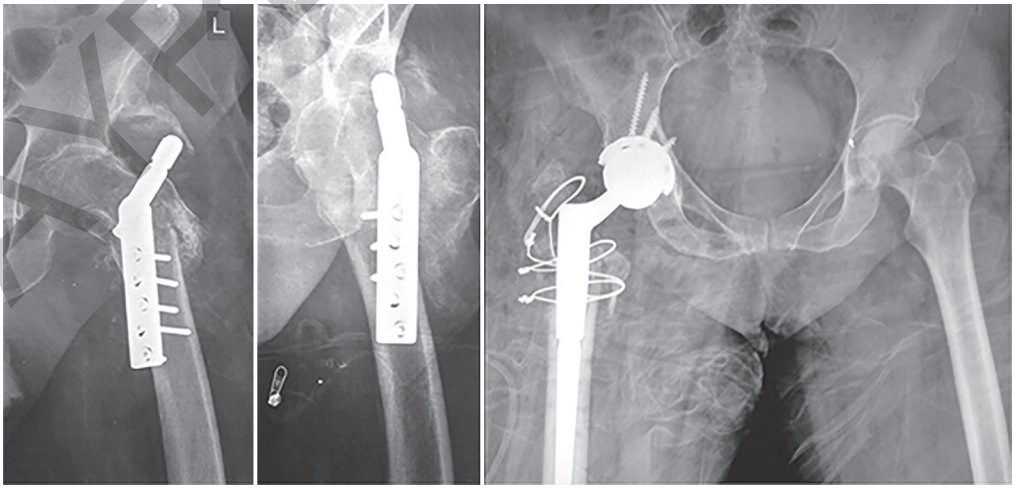


Fig 5: Failed hip fracture fixation, salvaged with arthroplasty.

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distal humerus, hip, and knee are regions where primary arthroplasty is often considered instead of fracture fixation. Cement arthroplasty is preferred in the setting of severe osteoporosis. It alleviates pain, allows immediate weight bearing ambulation and avoids issues with bone healing. However, arthroplasty in the setting of a fracture or failed fracture fixation is complex and often a massive undertaking requiring a high degree of expertise and experience. Also, the outcomes of arthroplasty in the fracture setting are inferior compared to those following primary osteoarthritis.

Medical Augmentation

Antiosteoporotic agents such as bisphosphonates and denosumab limit bone resorption and enhance callus formation.[15,16] When used in the setting of relative stability, these agents promote formation of exuberant callus and accelerate fracture healing. However, when used in conditions of absolute stability, bisphosphonates inhibit bone resorption, which in turn inhibit fracture remodeling and healing. This may lead to delayed union, nonunion, and fixation failure. On the other hand, bone forming agents such as teriparatide have been used to augment fracture healing and improve bone quality.

Metabolic Augmentation

Calcium phosphate is a building block and a substrate for bone. Adequate calcium and vitamin D intake is essential not only to improve bone quality, but also to promote fracture healing.

Intramedullary Strut Grafting

Strut autografts or allografts harvested from the fibula or the iliac crest have been shaped and inserted within the medullary canal at the fracture site typically in comminuted metaphyseal fractures to recreate the weight bearing column, prevent collapse and limit implant failure. For example, a 5-cm cortical strut is used within the proximal humerus to support the head **(Fig 6)**.[17] Together with anatomic reduction and plate fixation, it reduces the risk of varus collapse, and enables fracture healing without fixation failure.

Endosteal Plating

Rarely, in the setting of severe comminution and bone loss, a contoured endosteal plate is placed within the medullary canal along the

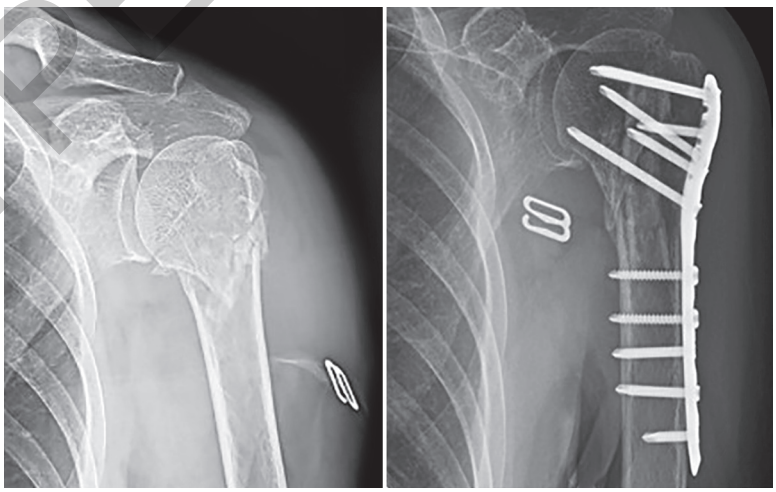


Fig 6: Fracture proximal humerus with medial comminution stabilized with a plate and augmented with a strut graft along the medial calcar.

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Fig 7: Periprosthetic fracture salvaged with a hip arthroplasty, extraosseous strut grafts, and circumferential wiring.

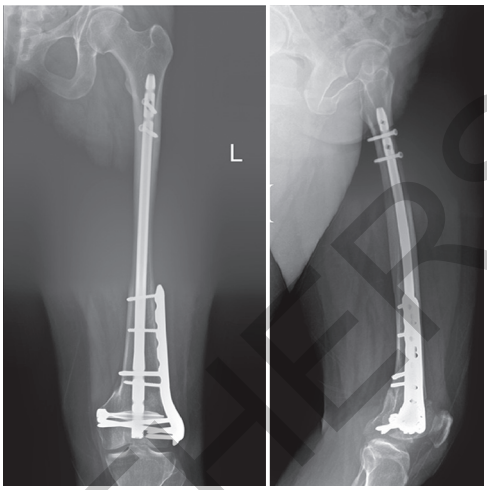


Fig 8: Metaphyseal plating to augment a supracondylar nail used for a distal femur fracture fixation.

medial cortex.[18] Screws are then placed from the extracortical plate on the lateral surface, through the lateral cortex, across the endosteal plate and the medial cortex. Bone graft is then inserted within the osseous defect.

Extraosseous Strut Grafting

Periprosthetic fractures in osteoporotic bone can be augmented by placing cortical struts circumferentially over the bone at the fracture site. The struts are held in place with circumferential wires **(Fig 7)** or screws locked to a small variable angled locking plate. The graft gets incorporated with the native bone with spot-weld osseous bridging.[19]

Nail-plate Combination

Although, intramedullary nails are preferred for fixation of diaphyseal fractures because of their load sharing properties, the stability offered may be inadequate when treating fractures within the proximal or distal tibia. In these cases, intramedullary fixation can be augmented by using a plate to better stabilize the shorter, metaphyseal fragment **(Fig 8)**. Interlocking screws can also be inserted across the nail through a percutaneously inserted plate to enhance screw stability.

Coated Screws

Schanz screws coated with hydroxyapatite have shown improved strength when used for external fixation. Research is awaited regarding the use of coated screws with nails and plates.

Challenging Osteoporotic Fractures

Fractures of Proximal Humerus

Proximal humerus fractures are typically seen in elderly patients with osteoporosis. Failure of fracture fixation is not uncommon. Risk factors for loss of reduction include osteoporosis, displaced varus fracture, loss of medial calcar support, inadequate fracture reduction, and humeral head ischemia.[20]

Obtaining an anatomic reduction, restoration of the medial buttress with an intramedullary strut graft, and use of precontoured locking

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compression plates which allow insertion of screws at variable angles so as to obtain maximum purchase within the head, is recommended. Screw pullout can be enhanced by placement in the subchondral bone, or use of bone cement injected through specially designed fenestrated screws. Use of sutures to anchor the rotator cuff to the plate enhances the fixation and promotes early resumption of mobility.[9,10]

Intramedullary multilock nails for proximal humerus fractures help prevent collapse seen with the use of plates. Locking screws also get a hold on the nail preventing migration and back out, thus enhancing the fixation in porotic bone.

Hip Fractures

Extracapsular osteoporotic hip fractures are a challenge to treat. The decision to be made is whether to replace or fix with implants. Fixation has a possibility of failure. Replacement with prosthesis in this setting is extremely complex and is associated with a higher rate of complications compared to arthroplasty for primary osteoarthritis. Biomechanical studies consistently show that cephalomedullary nails perform biomechanically better than sliding hip screws. The nail is closer to the weight bearing axis compared to plates, and due to short lever arm, it reduces bending forces by 30%.[21] The interlocking hip screw used with the nail allows controlled impaction of the fracture.[22] However, failure rates of even nails are not insignificant. Care must be taken to achieve anatomic valgus reduction, restoration of the anteromedial weight bearing column, optimum position of the nail within the medullary cavity, and accurate position of screw within the femoral head, ensuring an adequate tip-apex distance. For subtrochanteric fractures and reverse intertochanteric fracture, a long nail is preferred. For extremely unstable fractures, cerclage wiring, or auxiliary plates have been shown to improve biomechanical stability.[23] Novel nail designs with multiple interlocking lag screws provide improved mechanical performance over nails with single lag screws.[22]

Senior Author's (DDT) Comments

Metaphyseal Bone

Locking plate fixation is the main fixation for osteoporotic metaphyseal bones.

However, the design of the locking plate is such that all the locking screws are parallel to each other. In porotic bone, when the screws are not having purchase along one segment, all the parallel screws can back out if the fracture is unstable **(Fig 9)**. Possible solution is to make the fixation very stable by compression at the fracture site and minimum four screws in each fracture fragment using a long 10-hole plate. Metaphyseal locking screws can be put in different directions using a variable angle plate **(Fig 10)**. To prevent back out of the diaphyseal portion of the plate, put locking screws along with a few nonlocking screws that are not parallel to the locking screws **(Fig 11)**. Alternatively, ordinary screws can be placed at desired angulation and then locked with a locking cap **(Fig 12)**. Another option is to use bone cement to hold the screws in the bone. This technique is used frequently with pedicular screws in the spine **(Fig 13)**, and the sliding hip screw in the head of femur. Same principle can be used in long bones at times. First fix the plate to



Fig 9: Mode of failure of locked plates.

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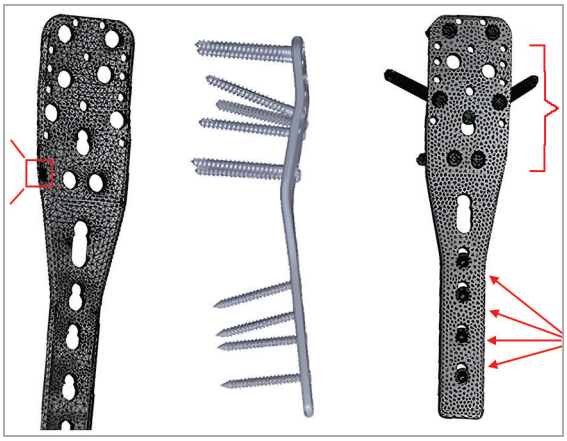


Fig 10: Variable angle locking plate.

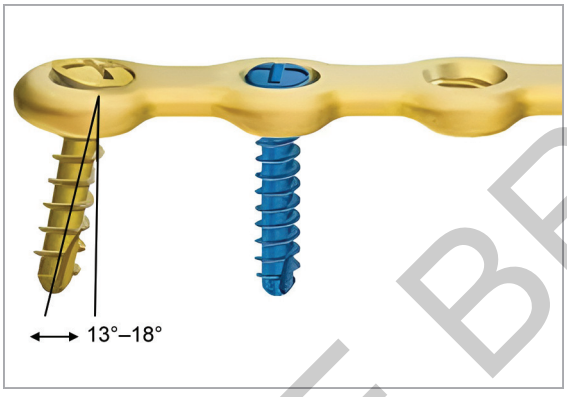


Fig 11: Nonparallel locking screws.

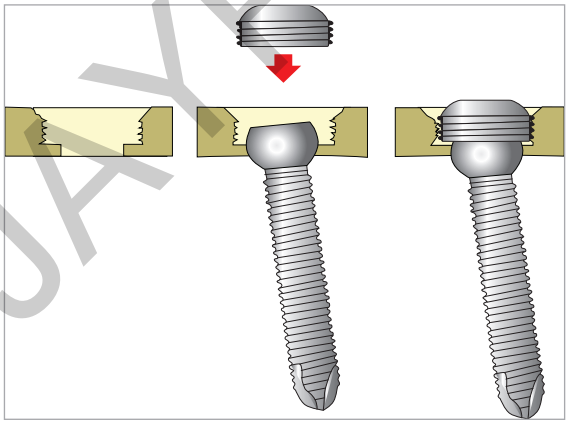


Fig 12: Nonparallel locking screws locked with a cap.

the bone using one or two screws in each fracture fragment. Now drill holes for the other screws. Inject a small amount of semiviscous cement into the holes and quickly insert screws into these holes before the cement becomes solid **(Fig 14)**.

Another option is to insert a fibular strut into the medullary canal. This lends stability at the fracture site and works as a scaffold for fracture healing. Cancellous autografts are usually added to stimulate osteogenesis. Additionally, screws inserted across the fibula, obtain a four cortex hold which improves their pullout strength. This technique is most useful in secondary osteoporosis after multiple operations mainly in humerus, and distal tibia **(Figs 15 and 16)**.

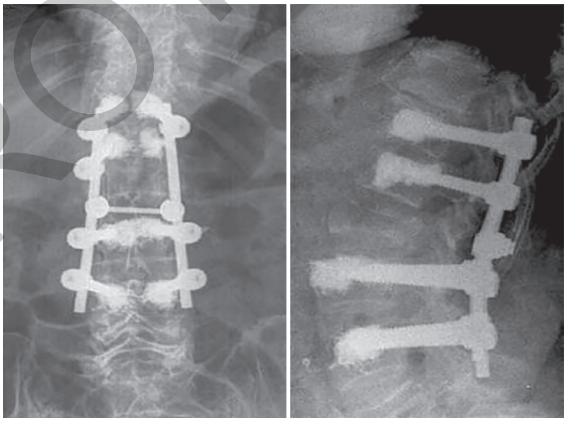


Fig 13: Cement augmented pedicle screws.

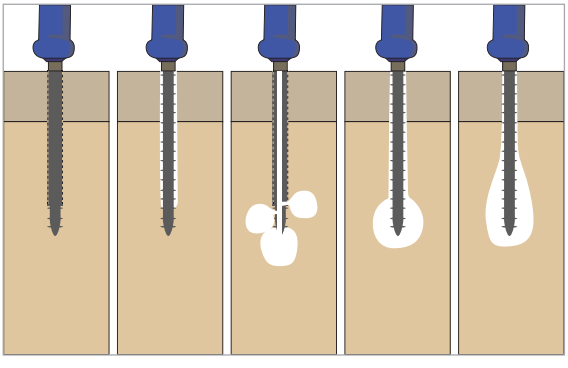


Fig 14: Cement augmentation of screws by various techniques.

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Diaphyseal Bone

Osteoporosis is observed in diaphyseal bones of elderly ladies or in multiple operated nonunions in a young patient who gets disuse osteoporosis due to prolonged nonweight bearing. An intramedullary nail combined with a plate is an excellent method of fixation in these osteoporotic bones. If the plate is long enough to extend beyond the inserted nail, the screws at the extremes of the plate will have a bicortical hold **(Fig 17)**. Where the plate and nail overlap, there may only be a unicortical hold of the screws **(Fig 18)**. Bicortical screws can be attempted by using thinner 3.5 mm cortical screws. Nail and plate is a wonderful fixation in most nonunions in the diaphysis of long bones, in osteoporotic and also in nonporotic bones.

In patients who have had surgeries earlier, the hourglass shape of the medullary cavity with a narrowing at the isthmus is lost. Instead, the

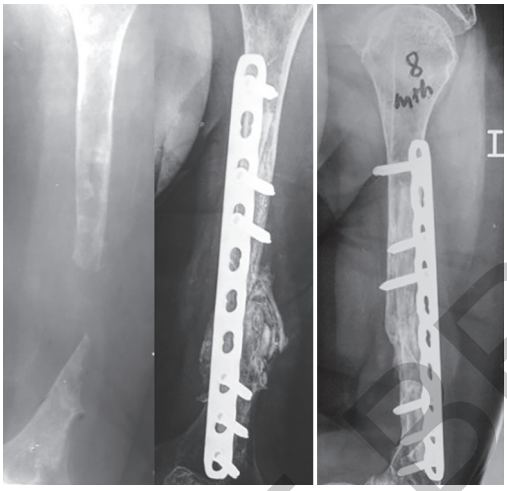


Fig 15: Failed fixation of proximal humerus salvaged with an intramedullary fibular strut graft and plating.

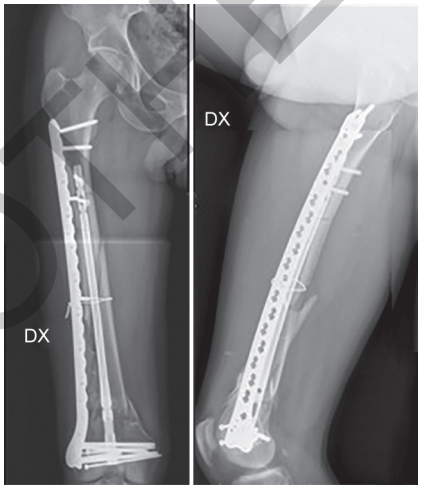


Fig 17: Comminuted distal femur fracture treated with a supracondylar nail and a locking plate with screws inserted proximal and distal to the plate.

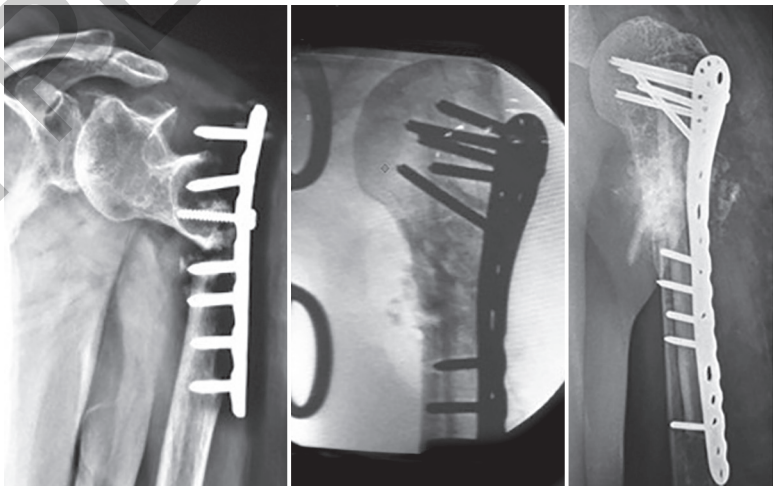


Fig 16: Atrophic nonunion of humerus shaft salvaged with an intramedullary strut graft, cancellous autograft, and plating.

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Fig 18: Nail-plate combination used for fracture femur shaft. Note the 4.5 mm unicortical screws and one 3.5 mm bicortical screw.

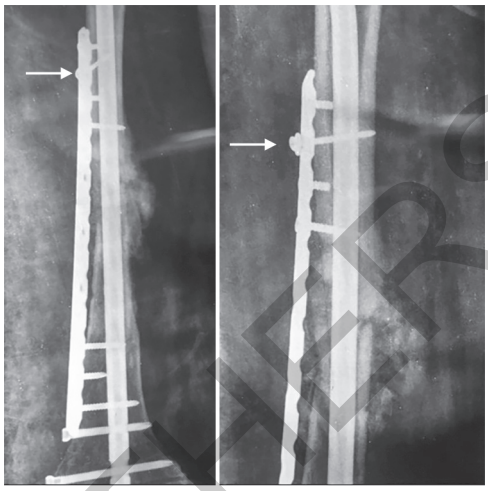


Fig 19: Nail-plate combination used for a femur shaft fracture. Note the 3.5 mm bicortical screws inserted through the 4.5 mm locked plate using a washer.

medulla is uniformly expanded because of cortical thinning. Even a large diameter nail, i.e., 13, 14, and 15 mm that otherwise occupies the medullary cavity, does not provide three point fixation. A nail and plate combination is the ideal fixation in these situations.

How to Execute a Nail and Plate Combined Fixation?

The diameter of the nail selected should be such that it maximally occupies the medullary canal, but still leaves space anterior or posterior to the nail for insertion of bicortical screws. Generally, the plate used is a 4.5 mm dynamic compression plate (DCP). 3.5 mm screws are used through the plate, so that they can be angulated anteriorly or posteriorly in order to miss the nail. To prevent 3.5 mm screws from sinking across the holes of a 4.5 mm DCP, washers are used over the plate to hold the screws **(Fig 19)**. Beyond the ends of the nail, standard 4.5 mm bicortical screws can be used through the plate. I start by inserting the guide wire for a 4 mm cannulated cancellous screw bicortically through the plate, without hitting the nail. The track is then drilled. The 3.5 mm screw with a washer is then inserted



Fig 20: Nail-plate combination used for a femur fracture. Note the distal interlocking screws have been inserted through the plate.

through the plate along the predrilled track. If the guide wire/drill hit the nail, the wire is redirected.

If possible, one of the screws must pass through both, the plate and the locking hole of the nail **(Fig 20)**. This can be achieved as follows:

- First past one screw in the nail to lock and stabilize it in the medullary cavity.

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- Drill a track for the locking screw in the other fragment.
- Insert a K-wire in this track.
- Put a plate over this K-wire aligning the plate hole with the locking hole.
- Pass the appropriate screw through the hole of the plate and the hole of the nail. This screw will act as a locking screw for the nail and also give a bicortical hold to the plate.
- It will be almost impossible to do the same thing for the second locking screw. If you can do that, consider yourself lucky and celebrate.

If there is not enough room to insert bicortical screws through the plate, though not biomechanically ideal, one may consider unicortical screws. Usually, 12/14 mm screws are used. These must be used in alternate plate holes, leaving an unused plate hole in between the screws. Since these screws are unicortical, they weaken the cortex predisposing to peri-implant fractures. Also, avoid using > 2 unicortical screws in each fractured fragment. At the extreme ends this plate can be fixed with bicortical locking screws. Relying only on unicortical screws to hold the plate, may not be a good idea, as sometimes these walk out **(Fig 21)**. This happens because at times the 14 mm screw is too long to lock in the plate or at others the 12 mm is too short to have any hold on the bone. It is necessary to get at least two bicortical screw holds through the plate on either side of the fracture, to prevent this from happening. Using the newer variable angle locking plate may overcome this difficulty to some extent.

At the end, all fixation done in osteoporotic bones in elderly should be treated for osteoporosis using teriparatide with/without denusomab as recommended by a medical specialist.



Fig 21: Failure of nail-plate construct when using a locking plate with only unicortical screws.

Conclusion

Fractures in the elderly present a unique challenge. The need for stable fixation and early weight bearing is directly hampered by the presence of osteoporosis resulting in suboptimal hold of implants. As a surgeon, one has to choose and tailor the treatment uniquely for each patient. The use of intramedullary implants has been shown to be better biomechanically than surface implants. Augmentation of screw hold by use of block graft, or locking screws helps. Cement to augment screws has its own long-term problems and is not a solution in the young osteoporotic bones. The use of a nail and plate combination will help in most situations and should be used wherever possible. Concurrent medical management of osteoporosis and enhancement of fracture healing will prevent long-term failure of implants in such patients.

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KEY POINTS

- Fractures in osteoporotic bone are often comminuted with complex fracture patterns. Reduction of the fracture often results in large bone voids that compromise stability of fracture fixation.
- Stable fixation of fractures is essential to create a mechanobiological environment for fracture healing. However, achieving adequate stability in osteoporotic bone can be challenging. Implants need to withstand loosening or be otherwise reinforced or augmented to prevent failure.
- Elderly patients have poor capability to cooperate with weight bearing limitations. Frequently, they also have poor balance and coordination. Hence, fractures need to be fixed so as to provide maximal stability in order to withstand immediate full weight bearing.
- Restoration of load bearing capability of the fractured bone by ensuring cortical continuity at the fracture site through anatomic reduction, alignment of fracture fragments, and if required, strut bone grafts is crucial to promote fracture healing, allow early weight bearing and reduce the risk of fixation failure.
- Primary stability must be achieved through robust fixation using load sharing implants, such as intramedullary nails or locked plates with a wide surface area and multiple screws.
- Secondary stability involves the use of additional implants to neutralize bending and torsional forces and augment the primary fixation.
- In metaphyseal bone, locked plates with multiple screws are the most reliable technique of fracture fixation. Additionally, intramedullary strut grafting or reconstruction with bone cement is recommended.
- In diaphyseal bone, fixation with a nail-plate device is currently the procedure of choice.
- Treatment of osteoporosis is vital to promote bone healing, improve stability of implants, and limit risk of peri-implant fractures.

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