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GERIATRIC ORTHOPEDICS (E MEINBERG, SECTION EDITOR)

Alternative Fixation in Osteoporotic Fractures

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Abstract
Purpose of Review The goal of this paper is to review the current available literature in alternative fixation in osteoporotic fractures, including the roles of locking plates, polyaxial screws, bone augmentation techniques, arthroplasty, and implant coating, as well as the role of co-managed care.
Recent Findings Bone mineral density has a definitive role in fixation failure in osteoporotic bone; in some regions, such as the femoral head, if the BMD is below 250 mg/cm^3, the failure rate will increase; if these areas can be identified and the fixation strength on them improved, the failure will decrease. In order to improve the fixation strength, several strategies have been explored: locking plates, polyaxial plates and screws, augmentation of the bone with cement or bone substitutes, implant coating, and at last, the use of arthroplasty as primary treatment in severe osteoporosis and periarticular and articular fractures.
Summary Osteoporotic fracture care continues to be a challenge, especially in fracture fixation. There has been recent improvement in the approach to these complex injuries, starting with orthogeriatric co-management models of care to improve patient care and outcomes. Additionally, surgical options have improved through advances in surgical techniques, augmentation of proximal femur and proximal humerus fractures, locking polyaxial implants, and improved coating of implants and arthroplasty.

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Introduction

With the increase in the global population of older adults, fragility fractures have emerged as an important orthopedic condition that affects both physiologic health and function. By 2025, costs of osteoporosis-related fractures in the USA will rise to approximately $25.3 billion [1]. The National Osteoporosis Foundation estimates that there are approximately 2 million osteoporosis-related fractures in the USA each year [2••]. Stabilization of osteoporotic fractures can be problematic. Despite optimal surgical techniques, the major technical problem is the difficulty in obtaining secure fixation of the implant to osteoporotic bone.

However, recent advances in care, implants, and technique have demonstrated improvements the orthopedic treatment of fragility fractures, which are the focus of this report.

Effects of Osteoporosis on Conventional Techniques or Internal Fixation

Osteoporosis, defined as a decrease on bone mineral density (BMD), has a definite role on the failure rate of fixation, as it affects fixation strength as screw pull out or cut through. Biomechanical studies assessed various implant configurations such as single screws, screw-plate constructs, and dynamic screw interfaces at different bone locations under different loading modes and concluded that failure of fixation is closely related to decreases of BMD measured by dual energy X-ray absorptiometry (DXA) [3, 4]. The most frequent reported complications related to low BMD are bone cut-out, secondary fractures, mechanical failure, pseudoarthrosis, loss of reduction and redisplacement [5, 6], with the most concerning being cut-out. Recent biomechanical studies concluded that there are very high risks of implant failure in trochanteric fractures when BMD is below 250 mg/cm^3 in the region of the femoral head [7••]. Therefore, one of the improvements for decreasing cutting-out in hip fractures would be to identify the areas where BMD is below 250 mg/cm^3 in order to improve their fixation, or to improve the relative bone structure in the region of fixation.

Implants Designed to Improve Fixation in Osteoporotic Bone

Locking Plates

Techniques for improving fixation in low bone mineral density have focused on changing from shear stress to compressive stress at the screw–bone interface by using locking plate technology. This technology has the ability to lock the screw head into the plate creating a unified construct which leads to the strength of fixation being equal to the sum of all screw–bone interfaces. Such a construct is four times stronger than a conventional non-locking system [8]. The greatest advantage of the locking plate is that if the screw–bone interface fails, the screw-plate interface remains intact [9]. Complete failure of fixation is still possible but only if all screws on one side of the fracture fixation fail simultaneously. Consequently, the locking plate has significant advantages in osteoporotic bone, potentially decreasing failures [10]. In a systematic review of the literature comparing conventional unlocked plates to locked plates, locked plate construct provided more stable fixation in osteoporotic bone [11].

Polyaxial Screws/Polyaxial Plates

One of the shortcomings of first generation locked plating was the constraint of only having screws with a predetermined or nominal trajectory (perpendicular to the plate), which restricted screw position into the bone segment or sometimes a fracture fragment that was not in the trajectory of the screw was not fixed by the locking head screw, and thus, secondary loosening of the screws might be associated [12, 13] This was especially true in periarticular fractures and in fractures around implants (either periprosthetic fractures or fractures around fracture fixation devices). Therefore, polyaxial screw holes were developed to allow for variations of screw trajectory while still providing a locked screw-plate interface. Variable angle locking plates were then introduced as a more flexible tool for fracture fixation in such challenging cases.

Variable angle locking heads are cup-shaped, allowing an inclination of the screw insertion angle up to 15°, and allowing for locked screw positioning within a conical trajectory volume. Lenz et al. [14] reported similar locking strength of polyaxial screws compared to fixed-angle locked plates when screw trajectories remained within a 0°–10° cone of angulation. However, at 15° of angulation and beyond, failure occurred resulting in the recommendation that screws should be placed with precaution beyond the 15-degree angulation.

Recently, Lampropoulou-Adamidou et al. [15] reported on the use of variable angle locked plate technology in acute distal femur fractures using a polyaxial locking system, where they reviewed 73 distal femur fractures, with 33 of these fractures occurring around previous implants (26 periprosthetic and 7 around implants). They had a 9.5% early postoperative complications rate but none of them due to the implant or variable angle technology itself, there were one deep surgical infection, 2 pulmonary embolism and 4 respiratory and urinary tract infections. At the final follow-up, all fractures had healed but they had 6.8% major revision surgery due to healing problems (4 exchange to a retrograde nailing and one to an angled blade plate) and 4.1% minor revision surgery (three patients required percutaneous application of bone marrow aspiration and BMP-7); they conclude that locking plate technology could be useful in difficult fracture situations in the distal femur.

Biomechanical models of osteoporotic bones comparing divergent, convergent, and parallel screw positioning have showed significant differences, favoring polyaxial positioning of screws in terms of average pullout stiffness: parallel positioning 66.7 N/mm, convergent 15ª 72.0 N/mm, divergent 15° 83.3 N/mm, and divergent 30ª 83.5 N/mm [16].

Augmentation

Fragility hip fractures, mainly intertrochanteric and femoral neck, are frequent in geriatric patients and are considered the most serious complication in osteoporotic patients [17]. Many patients do not achieve their previous functional status after fixation; they lose their function and autonomy [18, 19]. Because of inadequate bone quality, achieving a stable fixation is difficult, leading to a higher risk for failure [20]. Regardless of the fixation technique used, cutting-out and cutting-through are still the most frequent complications that affect patient functionality and may result in revision surgery [9].

Augmentation techniques have been developed to improve bone-implant stability, implant anchorage, and improve patient's clinical outcomes [2••, 17, 21, 22]. Studies evaluating the mechanical properties of augmenting standard fixation technique in intertrochanteric fractures with non-resorbable polymethyl methacrylate (PMMA) or resorbable calcium phosphate showed that augmentation confers distinct biomechanical advantages, but no difference between the different augmentation techniques. In addition, augmentation with

PMMA around femoral neck fracture implants increase the holding power significantly compared with augmentation with calcium phosphate cement [23, 24].

C. Kammerlander et al. [22] followed 62 patients for 15 months after osteoporotic pertrochanteric fracture treated with cement-augmented fixation. They used an implant (Proximal Femoral Antirotation Nail, PFNA, Depuy Synthes) with a perforated blade for neck-head fixation, which offered an option for augmentation with PMMA cement. A mean volume of 3.8 ml of cement was injected. The study showed that augmentation of the implant is a safe method, prevents migration of the implant, and led to good functional results without causing cartilage damage, intraarticular extravasation of cement, or bone necrosis.

Fracture fixation of proximal humerus in patients with osteoporotic bone is also a great challenge. Despite improved implants, secure anchorage of the implants in the trabecular bone of the proximal humerus remains demanding for the surgeon [2••]. Recent developments of cannulated and perforated screws in combination with angular stable plates allow fracture fixation in a conventional way and allow in situ augmentation of the screws with PMMA cement [2••].

S. Unger et al. [25] in a biomechanical in vitro study investigated the effect of in situ augmentation on implant anchorage in a three-part proximal humerus fracture model with reduced bone quality. Fracture fixation was carried out using an angularly stable plate and cannulated screws; in the control group, the four proximal screws were treated with four cannulated screws, each augmented with 0.5 ml of PMMA cement. The contra lateral side functioned as a non-augmented control. The humeral models were loaded in varus-bending or axial-rotation using a cyclic loading protocol with increasing load magnitude until failure. Augmented specimens showed a significantly higher number of load cycles until failure than non-augment specimens. They concluded that augmentation of cannulated screws is a reasonable method to enhance implant/screw anchorage in the humeral head with decreased bone mineral density.

G. Röderer et al. [26] developed a biomechanical in vitro assessment of screw augmentation in locked plating of a proximal humerus fracture mode. They measured local bone quality of a proximal humerus fracture model with a “DensiProbe” in the direction of the six proximal screws of a standard locking plate (the region of the lowest bone quality was augmented). Two screws aimed at a region of low bone quality were augmented, which was almost as effective as augmenting twice as many screws in a previous study. They concluded that screw augmentation combined with knowledge of the local bone quality could be more effective in enhancing the primary stability of a proximal humerus locking plate [26]. This study demonstrated the potential advantages of understanding local bone quality, potentially making it suitable for intraoperative use by allowing the surgeon to take measures to improve stability [27].

As mentioned earlier, hip fractures may be the most serious challenge in osteoporotic patients due to their frequency and need for weight-bearing recovery. Most augmentation studies are biomechanical while others describe an improvement in treatment outcomes; however, the clinical benefits and impact on functional outcome still need to be evaluated. Our team is developing a multicentered, randomized, single-blinded clinical trial in two trauma centers in Bogotá, Colombia to assess if augmentation with PMMA of fragility hip fractures improves radiologic and clinical outcomes in geriatric patients after 1-year follow-up. Since there is not sufficient evidence in clinical outcomes after augmentation, this study intends to generate evidence that might support the use of augmentation in the proximal femur when treating intertrochanteric fractures.

Arthroplasty

For older patients with severe osteoporosis or comminution, joint replacement is an excellent surgical option especially when there is pre-existing arthritis or when internal fixation is inappropriate [9]. There are definite advantages of prosthetic replacement over reduction and fixation of fractures. There are no restrictions for immediate ambulation and weight bearing, thus decreasing the incidence of post-operative complications, such as pulmonary infection, atelectasis and pressure sores [28]. Also, hip arthroplasty is an effective salvage procedure after the failed internal fixation of an intertrochanteric fracture in an older patient [28].

Implant Coating

Biological processes that enhance the healing potential of osteoporotic fractures should also be considered as an adjunct treatment [9]. Surface coating of implant can be used to enhance the attachment of the screw to bone. Many materials have been used but the most studied is a hydroxyapatite (HA)-coating [29]. The enhanced strength tends to be more pronounced in osteoporotic bone compared to non-porotic bone when using HA coating. Moroni et al. have shown a significant improvement in holding properties and less loosening of pins used for external fixation of extremity fractures when pins were coated with hydroxyapatite compared with conventional stainless steel or titanium pins [30, 31]. Studies have shown that HA coating on pedicle screws increased extraction torque by 20–100 compared to conventional screws with no coating [32, 33]. Additionally, combining a systemically delivered antiresorptive drug with an HA-coated implant optimizes the stability of the bone-implant interphase. A removal torque 2.5 times greater was demonstrated in HA-coated pins in patients who received systemic alendronate [34, 35].

Studies using local alendronate demonstrated improved quality of fixation in the bone-implant interphase. Histological examination in a canine model demonstrated a 1 mm zone of dense cancellous bone around the implants [36]. However, there is a possibility that a toxic concentration of the unbound bisphosphonate may not only inhibit osteoclasts and osteoblasts, and thus new bone formation; therefore, it is important that the concentration of bisphosphonate is below the toxic level [37]. The omission of not irrigating a bone cavity after soaking it in bisphosphonate could be potential deleterious. Further studies are indicated and ongoing.

Other coatings have also been studied. Type I collagen coating in in vivo models have shown a cellular response during the early stages of bone healing and bone remodeling directly at the surface of metallic implants without altering the mechanical stability [38]. New bone formation, number of osteoclasts and total bone contact around Titanium (Ti) pins coated with collagen/chondritin sulfate (CII/CS) in the rat tibia significantly increases after 4 weeks of implantation compared to uncoated pins [39]. However, not all novel coatings have been successful when tested in vivo such as gold [40], pyrolytic carbon, chromium, cobalt, molybdenum (CoCrMo) [41]. While promising, much more study is needed.

Multidisciplinary Treatment

A patient with a fragility fracture has compromised bone quality and is at risk for future fractures. Every fragility fracture patient should be evaluated for osteoporosis and started on treatment as indicated in order to reduce the incidence of recurrent fractures and to promote the stability of orthopedic implants [42, 43]. Before the implementation of programs for secondary fracture prevention, the rate of evidence-based treatment for osteoporosis after a fragility fracture was 2% but has now increased to 25% around the world [44], demonstrating continued low attention of physicians to secondary fracture prevention.

A multidisciplinary approach is an established approach to achieve recommended standards of care for fragility fractures. Some studies conclude that the implementation of a standardized multidisciplinary care plan can improve the outcome of fragility fractures, such as length of stay, time from emergency room admission to surgery, earlier weight bearing and increased attention of surgeons to secondary fracture prevention, decrease secondary fracture risk and mortality over time [45–47], additionally also has been shown to be cost-effective [47, 48]. In Latin America, where Orthogeriatric Care Programs are being implemented, mortality and survival rates of patients aged 65 years or older with fragility hip fractures are decreasing progressively. In one hospital in Bogotá, Colombia, mortality rates decreased from 23% in the first year after implementation of the program to 12% at the fourth year [49]. This is a significant achievement and a model that might be exported to other programs around the world.

Conclusion

In conclusion, new alternatives and techniques have been developed to address the challenge of fracture fixation in osteoporotic patients. These can be summarized as being related with techniques (bone augmentation), implants (locking plates, polyaxial screws/polyaxial plates, coating of implants, joint replacement implants), and orthogeriatric co-management models of care. Combination of these methods could enhance construct strength; decrease fixation failure and impact on patient's clinical outcome.

Compliance with Ethical Standards

Conflict of Interest Daniela Tafur reports grants from OTA, outside the submitted work.

Carlos Olarte reports payment as a speaker from DPS and Lilly and an international grant for research from OTA.

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Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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