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REVIEW ARTICLE

Evidence for Success with Locking Plates for Fragility Fractures

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Abstract Fixation of fragility fractures with plates and screws often results in loss of fixation and need for revision surgery. Locking plates and screw were introduced to improve fixation of fragility fractures and have been in use for a decade. This review was conducted to compile evidence that locking plates and screws improve fixation of fragility fractures. A search of PubMed was performed to identify biomechanical studies as well as clinical series of fragility fractures treated with locking plates. Biomechanics papers had to use models of osteoporotic bone and had to directly compare locking plates with traditional plates. Clinical studies included case series in which locking plates were applied to elderly patients with fractures of the proximal humerus and periprosthetic distal femur fractures. Most studies are retrospective case series. Locking plates lead to greater stability and higher loads to failure than traditional plates. When applied to proximal humerus fractures, uncomplicated healing occurs in 85% of patients. Constant and Dash scores approach normal values. For distal femoral periprosthetic fractures, union rates of 75% are reported with a malunion rate of 10%. Early evidence suggests that locking plates improve results of treatment of proximal humerus fractures and distal femoral periprosthetic fractures in the elderly. Loss of fixation is associated with failure to achieve stability at the fracture site. Principles of fracture fixation in osteoporotic bone defined prior to the introduction of locking plates should still be applied.

Keywords osteoporosis · fragility fractures · locking plates · proximal humerus · supracondylar femur fractures

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Level of Evidence: Theraputic Study Level IV

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Introduction

Many disorders result in decreased bone mass and deteriorated bone microarchitecture. These include genetic diseases such as osteogenesis imperfecta as well as acquired conditions such as osteomalacia, primary and secondary hyperparathyroidism, and chronic renal failure. Osteoporosis, however, is by far the most common cause of bone fragility. Regardless of the etiology of bone fragility in any given patient, the approach to care of fragility fractures are united by several common principles [8].

Osteoporosis is a systemic disease characterized by decreased bone mass and a deteriorated bone microarchitecture [17, 32]. It results in an increased fracture risk. Metaphyseal regions of the skeleton are composed of mostly cancellous bone which has a greater surface area for bone turnover compared with the compact cortical bone of the diaphysis. As a result, the metaphyseal regions lose bone more profoundly early after the onset of osteoporosis. Fractures resulting from osteoporosis generally involve the metaphyseal regions of the skeleton and result from low-energy falls. Osteoporosis is related to 75% of the fractures that occur in the elderly. Currently, 50% of women and 18% of men older than 50 years of age will sustain a fracture related to osteoporosis. In the USA, 1.5 million fractures are reported annually. Of these, there are 300,000 fractures of the proximal femur, 250,000 fractures of the distal radius, and 300,000 other fractures that occur through regions of the skeleton affected by osteoporosis. In 2004, the estimated cost of treating low-energy fractures requiring hospitalization was $24.2 billion [2]. In spite of this expenditure, less than 50% of hip fracture patients recover fully following their injury and treatment [9, 41, 48, 52].

These statistics emphasize the need for skilled fracture care in these patients. A reasonable return of function following fracture in the elderly often requires aggressive internal fixation and rapid rehabilitation. The need for stable internal fixation in osteoporotic bone is paramount.

The aim of the operative intervention in the treatment of osteoporotic fractures is to achieve stable fracture fixation that permits early return of function. For the lower extremity, this implies early weight bearing. Although anatomic restoration is important for intra-articular fractures, metaphyseal and diaphyseal fractures are best managed by efforts to primarily achieve stability rather than anatomic reduction [5, 8].

Appropriate treatment of fractures, which occurs secondary to osteoporosis, requires an understanding of the effect of this disease upon the material and structural properties of bone as well as any effect upon the process of fracture healing. An age-related decline in the capacity for fracture repair has been reported [18, 47]. A disturbance of the development of strength within the fracture callus has been reported in experimental models in the rat [18], but little is known regarding the effect of osteoporosis and its causes upon the process of fracture repair in humans [31]. Nonetheless, surgeons can assume that fracture healing in osteoporotic patients is impaired. Whenever possible, the principles of biologic fracture repair should be applied [33]. These principles include careful handling of the surrounding soft tissues avoiding unnecessary stripping of fracture fragments to preserve blood supply to the fracture site. In addition to minimizing the surgical exposure of the fracture preservation of the fracture, hematoma may speed the development of the fracture callus. Adherence to these principles may improve the speed of healing, improving the odds in the race against fixation failure

The primary mode of failure of internal fixation in osteoporotic bone results from bone failure rather than implant breakage. Since bone mineral density correlates linearly with the holding power of screws, osteoporotic bone often lacks the strength to hold plates and screws securely [1, 3, 47, 48]. Furthermore, comminution can be severe in osteoporotic fractures. Surgical treatment of fractures of the proximal humerus, proximal and distal femur, and the proximal tibia has historically yielded a high incidence of poor results in elderly, osteoporotic patients. For example, plate fixation of proximal humerus fractures in an elderly patient group results in fair to poor results in over 50% of cases with screw loosening and pull out from the humeral head occurring in at least one fifth of cases [29]. Intertrochanteric fractures of the proximal femur typically fail internal fixation in 10% of cases with the mode of failure being cut out of the lag screw from the cancellous bone of the femoral head [4, 14]. Although open reduction and internal fixation yields superior results to non-operative management in supracondylar fractures of the femur, 25% of these fractures treated with the angled blade plate result in fair to poor results due to loss of reduction from loosening of the implant in the osteoporotic bone of the femoral condyles [5, 40, 46]. Traditional techniques of internal fixation must be modified in order to achieve satisfactory results in osteoporotic bone. Internal fixation devices that allow load sharing with host bone should be chosen to minimize stress at the bone–implant interface. For these reasons, sliding nail plate devices, intramedullary nails, antiglide plates, and tension band constructs are ideal for osteoporotic bone [8, 9, 22]. Traditional plates and screws achieve stability by direct compression against the periosteal surface. Friction is responsible for the stability achieved between the plate and bone. Screws act individually to add to the friction force. If the forces applied to the construct exceed the friction force, the plate will begin to loosen. Likewise, as a result of cyclic loading of the construct, screw loosening occurs leading to deterioration of the stability of the construct [15].

Recently, a new paradigm in plate design, the locking plate, has emerged with particular advantages for the fixation of osteoporotic fractures. Locking plates are designed with screws that thread into the plate creating fixed-angle anchorage of the screws into the plate. Locking plates behave mechanically more like external fixators in that they achieve stability without the need for direct contact with the periosteal surface. In addition, the screws act in concert gaining purchase in regions of bone rather than individual sites as with traditional screws. In locking plates, screw failure is an all or nothing event. As a result, locking plates have greater resistance to failure especially in osteoporotic bone [15, 24, 40]. The traditional devices mentioned above as well as the new locking plates when combined with surgical tactics that adhere to the principles of biologic fracture repair can achieve excellent results [22].

Locking plates have now been in use for over a decade. Prior to their introduction, there was considerable evidence that for some fractures, especially the proximal humerus, internal fixation offered little real benefit to patients compared with non-operative care [10–12]. This presents an opportunity to review the current evidence of their effectiveness and to demonstrate if they provide a real advantage over traditional plate and screw technologies and techniques. The purpose of this review is to compile the evidence that locking plate fixation has a biomechanical advantage providing greater resistance to fixation failure in osteoporotic bone compared with conventional plating. We also sought to produce evidence that locking plate designs provide improved rates of healing with fewer instances of fixation failure in fractures related to bone fragility including the proximal humerus and the distal femur including periprosthetic fractures. The tertiary purpose of the review was to compile evidence that the better rates of healing and lower loss of fixation has translated into better functional outcomes for patients with these fractures.

Methods

Both in vitro biomechanical studies and studies evaluating the outcome of internal fixation of fragility fractures were sought. For clinical studies to be included, at least five subjects were required, and subjects had to be identified as older than 65 years or as having a history of osteoporosis or other fragility associated bone disease. Case reports were excluded as were manuscripts that were not written in English. Non-systematic reviews such as American Academy of Orthopedic Surgeons Instructional Course Lectures were not included, but the reference lists were studied for otherwise unidentified papers. The Medline database was used. Search terms included osteoporosis and fracture fixation, fragility fracture fixation, locking plate, proximal humerus and locking plate fixation, and distal femoral fracture and locking plate fixation.

Biomechanical studies that were included could utilize either cadaveric or synthetic bone models which simulated osteoporotic bone. To be included, the experimental methods had to include a direct comparison of locked plating methods with conventional plating methods. Clinical studies including retrospective reviews, case-controlled studies and meta-analyses were sought.

For biomechanical studies, comparisons of maximum load to failure and fatigue failure were assessed. For clinical studies union rate, complications related to the hardware such as loss of fixation, fracture displacement, or penetrations of the hardware through the bone surface were recorded. In addition, functional outcome scores achieved in follow-up were assessed. The primary purpose of assessing clinical outcome was to estimate the degree to which function was achieved compared with the pre-operative assessment or comparison to accepted population norms.

Results

The literature search produced 51 citations that included the keywords osteoporosis, fragility fractures, locking plates, proximal humerus, and supracondylar femoral fracture. After applying our inclusion and exclusion criteria, we identified five in vitro biomechanical studies and 16 studies of proximal humerus fractures and distal femoral periprosthetic fractures in which the results of fracture repair using locking plates were reported.

Five papers summarizing in vitro mechanical testing of comparisons of the stability and load tolerance of locked plates compared with traditional plates were identified [27, 35, 49, 53, 54]. Osteoporotic cadaveric bones as well as synthetic bone models designed to mimic osteoporotic bone were used. Four of the models used gaps to simulated comminution [27, 35, 53, 54], and all studies tested the constructs in cantilever bending, and axial and torsional loading. One study compared locked plating with application of the plate to the lateral distal fibula to a conventional plating using the posterolateral antiglide positioning of the conventional plate [35]. In the presence of a gap simulating comminution, all the studies demonstrated that locked plate constructs are stiffer, have greater resistance to torsion, and withstand cyclical loading to a greater degree. The locked plates in a cadaveric bone study presented a bending stiffness that was 50% greater than the conventional plates [54]. In models of cadaveric bone where the degree of osteoporosis differed between specimens, the advantage of locked plates was greater in specimens with lower bone mineral density [27, 35, 54]. Furthermore, in all studies the mode of failure of locked plates was different from conventional. In conventional plates, loosening developed as single screws usually farthest from the gap loosened and lost torque or stripped out of the bone. In locked plating, failure occurred with multiple screws cutting out simultaneously or by breakage of the host bone at the end of the locked plate. One study evaluated the role of angled screws which have an advantage in conventional plating. Angled screws through conventional plates can improve stability and fixation. By design, locked plates do not allow the surgeon to independently angle screws so this advantage is potentially lost. Locked plates tolerated higher loads than conventional plates with various patterns of angled screws. Furthermore, the advantage of angles screws appears to be lost in osteoporotic bone [54].

The most enthusiastic application of the locking plate and screws has been in the fixation of proximal humerus fractures. Since 2006, nine case series have been reported in ten publications [13, 19, 42, 43, 45]. One series was reported on twice [28, 50]. One systematic review [51] has been published. In the accumulated experience of the nine case series, the results of treatment of 726 patients have been documented focusing on the rate of union, rate of need for re-operation, intra-articular screw penetration, and analysis of functional outcomes using the Constant score with four studies also reporting on the DASH score [6, 28, 39, 50]. One study documented the EO-5D quality of life index [39]. A systematic review was published in 2009 and analyzed similar data [51]. The experience reported by these papers would suggest that uncomplicated healing can be expected in approximately 80% of cases. Secondary fracture displacement resulting from failure of fixation was noted to range from zero percent to 14.8% with one series reporting an unusually high rate of 64%. Screw penetration in to the glenohumeral joint through the humeral head articular surface was very consistently seen to occur in 11% to 15% of cases. The need for re-operation was generally prompted by secondary fracture displacement or symptomatic intra-articular screw penetration. Re-operation rates range from 3.7% to 19%. The reported Constant scores at the final examination after recovery varies between the reported series. In two series [6, 28, 50], the patients with an average age of 75 years achieved Constant Scores of 70 and 72 1 year following surgery which is within the range of normal for this age group. The cumulative Constant score reported in the systematic review was 74 [51]. Two series with patients of similar age report scores of 61 [39] and 62 [7] reflecting deficits of shoulder function. The three series reporting DASH scores found scores of 32 [27, 39, 50], which suggests mild shoulder dysfunction. In the series reporting the EQ-5D [39], patients reported a significantly lower overall quality of life compared with the pre-fracture state. In an analysis of failures reported in one paper, the most consistent factor associated with failure was lack of medial contact between the humeral head and metaphysis [34]. Absence of medial support was noted as a suspected factor in poor outcome throughout the reported series.

The other fracture type which has been addressed by the locking plate includes periprosthetic fractures of the distal femur including occurring above a total knee arthroplasty. Since 2006, five publications have addressed treatment of supracondylar fractures using locking plate designs. There are four case series [16, 20, 26, 38, 44] and one case-controlled study in which several methods of fixation were compared [30]. A total of 125 cases have been reported on. Average ages of the patients in these series ranged from 69.4 to 76.7 years. All the studies reported on the success of achieving union with the overall union rate being 77.6%. Malunion was reported in seven of 72 cases [30, 44], suggesting a malunion rate of 9.7%. The case-controlled study reported fewer nonunions, malunions, and complications in the locking plate groups compared with those in the traditionally treated group [30]. In one case series, complications were associated with diabetes and obesity [44].

Discussion

The aim of this review was to garner both in vitro and clinical evidence that fixed-angle, locking plates provide improved fixation for osteoporotic fractures. The biomechanical evidence consistently documents that locking plates provide stronger anchorage with better resistance to failure than conventional plates, and this advantage is increased as bone fragility increases [53, 54]. In the clinical setting, locking plates have provided effective fixation for traditionally difficult to treat proximal humerus fractures and periprosthetic fractures above total knee arthroplasties. Several case series of both types of fractures suggest that these new plate designs, when properly applied, can lead to successful union and restoration of function in elderly patients. In the case of proximal humerus fractures, approximately 80% of the fractures heal without complications, and on average, shoulder function approaches normal age-related function as judged by the Constant and DASH scores at 1 year. As for supracondylar periprosthetic fractures of the distal femur, 75% of fractures can be expected to heal with 10% or less resulting in malalignment (Table 1). Few of the case series provide direct comparisons between locking plate and conventional plate designs, so referencing historical information from the literature is the only basis for comparison.

The weaknesses evident in this review stem from the weaknesses of the studies reviewed. The biomechanical data has limited clinical applicability as none of the studies provide mechanical parameters that are arguably a surrogate for relevant biological loads experienced in the various anatomic sites where these plates are used. Furthermore, none of the loading regimens can represent the entire range of loads experienced in vivo. The clinical studies are primarily case series with only one study including a control group for comparison [30]. None of the studies stratify the results according to fracture type or complexity or for the severity of the subjects' age and bone fragility.

It is the authors’ opinion that, in spite of the lack of concrete evidence, it is clear that locking plates designed for the proximal humerus and distal femur are superior to traditional plates, especially in the osteoporotic patient. Additionally, although not specifically addressed by these studies, the anatomic designs make the surgical technique simpler and more reproducible and allow for less invasive plate applications [21, 25]. Traditional plates suggested for use in proximal humerus fractures had poor holding power and were quite bulky often creating acromial impingement [24, 29]. Many alternative techniques were devised due to the failure of these plates. These included tension band constructs, percutaneous pins, or flexible pins inserted retrograde into the humeral head [9, 36, 37]. Tension band constructs for the proximal humerus led to predictable healing, but 16% of patients had fair or poor functional outcomes [9]. Although these results appear to match the results of locked plating, the tension band techniques were technically demanding and required a greater surgical exposure of the fracture. Non-operative treatment has been advocated by some authors arguing that equivalent functional results can be achieved in the majority of fractures with the exception being the grossly displaced fractures with dislocations of the head or tuberosities. Court-Brown and his colleagues [10–12], advocates of non-operative management of many proximal humerus fracture types, have acknowledged the superior fracture fixation afforded by the proximal humerus locking plate but still question the indications for surgical care of the majority of these injuries. They have reported Constant scores of approximately 70 for most two-part and impacted three-part fractures treated without surgery at 1 year after injury. They also found that age was a critical factor in assessing functional outcome. Older patients have natural declines in Constant scores. Any assessment of surgical treatment of fractures of the proximal humerus should be stratified by age. After review of the Edinburg experience, it is quite obvious that a portion of the excellent results reported in these series of fractures treated by locking plates could have been achieved with non-operative care [10–12]. The true value of these plates will have to be tested in studies that are carefully controlled for age and bone fragility as well as for fracture classification.

Locking plate designs do provide enhanced fixation in fragile bone but cannot be expected to perform in situations

Table 1 Compilation of evidence supporting use of locked plates

Fracture type	Number of publications	Number of patients	Avg. age, years	% Healed	% Malunion	Function
Prox. humerus	9	726	75	80%	20%	Constant scores 61–72, Dash 32
Distal femur periprosthetic	5	125	60–76	77%	10%	NA

where the applied loads to the fracture repair exceed the strength of the host bone. This is evidenced by the relatively high incidence of intra-articular screw penetration through the humeral head [6, 50] and failure of fixation when the medial metaphyseal buttress opposite the plate is not established [6, 23, 34]. Prior to the introduction of locking plate technology, the guiding principle for fixation of fragility fractures was to share load between the host bone and fracture implant [6, 22]. When using plates and screws, this implied establishing contact of the opposing fractured ends for stable load bearing, creating the tension band effect with avoidance of buttress plating with gaps or comminution in the cortex opposite the plate. Tactics such as positioning plates in an antiglide position enhanced stability. In fact, one study in this review suggests that use of the antiglide position for traditional plates applied to the distal fibula achieves superior stability compared with use of the locking plate applied laterally [35]. The enhanced fixation achieved by the proximal humerus locking plate cannot eliminate the need to utilize the principles of creating stability at the fracture site, creating the tension band effect whenever possible and avoiding cantilever bending which will occur if the medial support of the fracture is not recreated.

In summary, the locking plate design has improved surgeons ability to achieve stable fixation in osteoporotic bone. This combined with anatomical plate designs have lead to successful repair of proximal humerus and periprosthetic fractures about the knee. However, failure of fixation and intra-articular penetration of implants occurs regularly as evidenced by the 15% incidence of this problem in nearly all the case series encountered in this review. Although these plates allow less invasive approaches which may benefit soft tissue healing, stable fracture reduction must be achieved to avoid complications of fracture fixation. For the proximal humerus fracture, this implies restoring the medial buttress opposite the plate. The experience of the proximal humerus fracture and the locking plate emphasizes that the principles of fracture fixation in osteoporotic bone learned from traditional plates and screws must not be forgotten.

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