Innovations in Locking Plate Technology

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Abstract

Plating techniques remain the mainstay for managing most periarticular and selected long bone fractures. However, movement toward more biologically appropriate plating techniques is occurring in an attempt to minimize soft-tissue stripping, decrease the need for bone grafting, and improve union rates. Internal fixation with locking plates creates a toggle-free, fixed-angle construct. Early data on the biomechanical and clinical performance of these implants are encouraging. Current indications for locked plating include periarticular fractures, typically those with metaphyseal comminution. Although impressive union rates have been reported, malunion remains a concern, especially when percutaneous techniques are used. Further clinical and biomechanical research on locking plate technology is needed to define its place fully alongside existing technology in orthopaedic trauma.


The philosophy and techniques of open reduction and internal fixation of fractures have evolved during the past several decades.1-3 To achieve functional rehabilitation of the limb, anatomic reduction, rigid internal fixation, and early joint motion historically were stressed.1-3 Although constructs were quite stable biomechanically, healing often was delayed because of the extent of soft-tissue dissection and bony devascularization required. Indirect reduction was introduced in the 1980s by Mast et al4 and others5,6 in an attempt to decrease surgical dissection by relying on ligamentotaxis, blind repositioning of fragments, reduction aids such as the femoral distractor, and other methods to maintain soft-tissue integrity and preserve bony perfusion. Additionally, plates were redesigned to limit contact with the underlying bone and further preserve bony vascularity.2 In the 1990s, Krettek et al7 popularized minimally invasive percutaneous plate osteosynthesis techniques using conventional implants placed through small incisions and submuscular tunnels. Cadaveric studies demonstrated better preservation of periosteal vasculature with these minimally invasive methods than with standard open exposures for internal fixation.8 As part of the continued development of biologically friendly plating, and to facilitate minimally invasive plating techniques, the use of plates that allow screws to lock into the plate to create a fixed-angle construct is gaining popularity. Understanding the biomechanics of these devices is necessary to appreciate fully the current indications, clinical results, and complications of locking plate technology.

Historical Perspective

Certain periarticular fractures, such as the comminuted distal femoral fracture, historically have been difficult to treat. The distal fragment is short, and options for fixation often are limited because of the concurrent presence of lag screws or coronal fracture planes. Any internal fixation device must provide coronal plane stability to maintain correct alignment during healing. Several 95° fixed-angle devices, such as the blade plate or dynamic condylar screw, have been used successfully to manage such injuries; however, these devices cannot be used in all situations. This shortcoming necessitated the development of other methods to achieve fixed-angle or “locked” internal fixation constructs.

Early attempts to gain angular stability of conventional screws placed through commercially available plates led to the development of the Schuhli nut (Synthes, Paoli, PA).9 This device, essentially a threaded washer, served two purposes: it allowed screws to lock to the plate, therefore preventing screw toggle, and it limited the contact of the plate with the underlying bone in an attempt to preserve periosteal perfusion. The results of biomechanical studies and clinical series have documented the improved stability and clinical utility of

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these devices in managing difficult nonunions and malunions. A locking plate prototype developed by Koval et al, consisting of threaded nuts welded to the distal aspect of a condylar buttress plate (Synthes), was intended to improve the fixation stability of distal femoral fractures in elderly patients. In a cadaveric model, the authors documented the biomechanical superiority of this locked construct over an identical but unlocked plate as well as over a 95° fixed-angle blade plate. Concurrent plate designs continued to minimize the contact between the undersurface of the plate and the bone. The point contact fixator device (PC-Fix; Synthes) incorporates unicortical screws that lock into a plate using a Morse cone mismatch that prevents screw toggle as the screws are tightened to the plate. The undersurface of the plate is undercut to allow minimal points of contact with the bone, further reducing bony devascularization. Initial biomechanical testing and a recent prospective randomized clinical trial revealed no significant difference between the performance of the PC-Fix and conventional bicortical plate constructs.

Multiple European clinical series have documented high union rates and low complication rates using the PC-Fix for fractures of the forearm. Locking plate technology has also been used successfully in both oral maxillofacial surgery and spine surgery, where stability is required without bicortical screw purchase. Success with such devices led to the development of anatomically precontoured locking plates designed primarily for periarticular fractures of the lower extremity, for which fixed-angle stability is frequently desirable because of metaphyseal comminution.

The development of locking plates has resulted in relatively unusual fixation constructs of long plates that use few, often unicortical, screws. Understanding the design rationale and potential clinical applications of such unconventional plates requires a basic understanding of the biomechanics of plate fixation.

## Biomechanics

The aspects of load transmission across a fracture stabilized with a locking screw plate device have not been studied; however, comparison to existing devices demonstrates the theoretical, practical, and comparative advantages of the locking plate. To understand this comparison requires an appreciation of the concepts of working length, mechanics of standard plate stability, and the effect of cantilever bending.

The working length of a plate-bone construct is defined as the length of plate unsupported by bone because of comminution, segmental bone loss, or other reasons. Bridge plates span large areas of comminution and thus typically have long working lengths. Although biologically advantageous because they help preserve soft tissue, such constructs are often at a mechanical disadvantage, especially when they are used for periarticular injuries, a common application. These fractures frequently have short periarticular fragments and long working lengths; the result is coronal plane instability and consequent collapse when standard nonlocking plates are used. To avoid this, a fixed angle must be provided between the plate and the fixation into the periarticular segment. This can be achieved with 95° fixed-angle devices. The locking screw-plate design facilitates a similar mechanical advantage with multiple points of screw fixation. This is most important in fractures with long working lengths, short periarticular segments, and the absence of bony support on the side of the fracture opposite the plate.

When standard bicortical screws are applied through a plate, the tightening of the screws compresses the plate onto the bone. The stability of this construct results from friction between the undersurface of the plate and the bone (Fig. 1). Because the screws are free to toggle in the plate, stability requires bicortical purchase of these screws. However, with a locking plate construct, threads on the screw head lock into corresponding threads on the screw hole of the plate (Fig. 2), eliminating toggle. The forces are transferred from the bone to the plate across the screw-plate threaded connection (Fig. 1, B). Compression of the plate to the underlying bone therefore is not required to achieve construct stability, and the blood supply to the bone directly under the plate is preserved. Accordingly, bicortical purchase is less important than with nonlocking plates. Avoiding bicortical drilling also theoretically minimizes further damage to the endosteal circulation and may decrease the risk of refracture after plate removal.

Current locking plate designs have used self-tapping unicortical screws (PC-Fix, Less Invasive Stabilization System [LISS]; Synthes); this has eliminated the need to measure the length for percutaneous screw insertion, has decreased inventory, and has minimized surgical time.

Full understanding of the mechanics of locking plates and unicortical screws requires an appreciation of the prevailing forces these fixation constructs must withstand in different anatomic regions of a bone. Bone quality is less dense in the metaphysis than in the diaphysis. Therefore, locked screws usually are placed in long rows perpendicular to the applied load and the limb axis. When, in a medial bony defect, a cantilever bending force is applied, the screws function like small blade plates, resisting the bending moment. Under the same circumstances, standard screw-plate fixation allows toggle and thus progressive varus deformity. In the diaphysis, locked screws also can be inserted perpendicular to the axial load, but they are then more com-
monly loaded in shear, similar to the prevailing conditions when half pins are inserted for external fixation. The pullout strength of a unicortical locked screw is about 60% the strength of a standard bicortical screw. In fact, a locked screw-plate construct can be thought of as being similar to an implanted external fixator. Studies of the biomechanics of monolateral external fixation have shown improved stability of constructs that incorporate wide spacing of half pins and placement of the connecting bar as close to the bone as possible. A locking plate construct might be considered the ultimate external fixator, with minimal soft-tissue dissection, wide screw spacing, locked screws, and the plate functioning as the connecting bar, placed extremely close to the mechanical axis of the bone. Although a direct comparison has not been made, the ability to move the plate closer to the mechanical axis should markedly increase stability compared with a monolateral external fixator, in which the bar is far from the limb axis, creating a large bending moment.

Few biomechanical studies have been published that compare current locking plate designs to conventional implants. One recent study compared the LISS distal femoral plate to the 95° angled blade plate and a retrograde nail in osteoporotic cadaveric specimens; the LISS was biomechanically superior in axial catastrophic load to failure testing. Marti et al compared the LISS distal femoral plate to the dynamic condylar screw and the unlocked condylar buttress plate; the LISS demonstrated superior ability to resist applied loads and had less irreversible deformation. Although limited, these early biomechanical studies demonstrate that locking plates can provide stability comparable or superior to current commercially available fixed-angle devices.

**Indications and Techniques**

The current indications for locking plate fixation are complex periarticular fractures, especially those with comminution of the metaphyseal region. Comminuted distal femoral fractures with multiaxial articular involvement are excellent indications (Figs. 3 and 4). Locking plates allow the surgeon more options for fixed-angle fixation while avoiding previously placed lag screws or fracture lines, such as the coronal (Hoffa) fracture of the distal femur. In the past, these obstacles sometimes precluded the use of traditional fixed-angle devices, such as the blade plate or the dynamic condylar screw. Bicondylar tibial plateau fractures, in which coronal plane stability is required, may benefit from this type of fixation (Fig. 5). In some patients, use of a lateral locking plate is an alternative to double-plating techniques. Locked plating also may provide an alternative to external fixation, thus minimizing associated complications such as pin-site infection and patient tolerance. The importance of anatomic reduction of the articular surface with lag screw fixation remains paramount. The metaphyseal comminution is then “bridged”
by the plate with locked screw fixation of the articular segment and with either locked or conventional bicortical screw fixation of the diaphyseal segment20 (Figs. 3 through 5). Great care is taken to preserve soft-tissue integrity, and therefore bony viability, in the metaphyseal region, regardless whether an open or a percutaneous submuscular plate application technique is chosen.

Other potential indications for locking plate technology include periprosthetic fractures involving total knee arthroplasty.30-32 Retrograde intramedullary fracture fixation is difficult to use with posterior cruciate ligament–substituting total knee arthroplasty designs because of the closed femoral housing. Lugs, stems, or other portions of the femoral component also may preclude the use of fixed-angle devices, such as the blade plate or dynamic condylar screw. Locking plates afford fixed-angle stability and permit the use of multiple distal locked screws, which often can be inserted around such obstacles and provide stable distal fixation even for very short distal fragments.

In some series, extra-articular or simple intra-articular fractures of the distal femur and proximal tibia with short periarticular fragments have demonstrated unacceptable rates of malalignment with intramedullary nailing.33,34 The use of locked plating constructs may provide improved fixation in these patients and result in less malalignment. If intramedullary nailing cannot be used for selected long-bone fractures with long working lengths, a bridge plate technique with locked screw fixation may be a viable alternative. Other evolving applications for locking plate technology include fixation of corrective osteotomies, malunions, and nonunions, as well as applications for orthopaedic oncology and other difficult fractures, such as the comminuted proximal humerus and distal radius; however, published clinical data for these applications are currently lacking.

**Disadvantages and Complications**

Several potential disadvantages of locking plate fixation exist. When tightening the screws, the surgeon has...
no tactile feedback as to the quality of screw purchase into the bone. Because they lock into the plate, all screws abruptly stop advancing when the threads are completely seated into the plate, regardless of bone quality. In addition, current locking plate designs can be used to maintain fracture reduction but not to obtain it. This is in sharp contrast to traditional techniques of internal fixation using blade plates or dynamic condylar screws, in which the 95° angle of the implant can be used as a reduction aid.\(^5\),\(^6\),\(^20\) For example, for the complex distal femoral fracture, the distal fragment can be prepared to accept a dynamic condylar lag screw or a blade plate by placing the implant exactly parallel to the knee joint.\(^35\) When the side plate is applied, limb alignment will be correct.\(^1\),\(^3\) With current locking plate designs, the fracture must be reduced and the limb alignment, length, and rotation must be set properly before placement of any locked screws.\(^20\) Once a locked screw is placed above and below a fracture line, no further reduction adjustment is possible unless the screws are completely removed. Locked screws will not “pull” the plate down to bone. This lack of construct reduction capability, combined with percutaneous plating techniques, can result in higher rates of fracture malalignment than occur with formal open reduction and internal fracture fixation.\(^36\) New techniques are evolving to facilitate the accuracy of closed reduction of such difficult fractures. Surgeons contemplating a percutaneous approach should be experienced in conventional open techniques and be cognizant of the differences.

Another concern is the rigidity of a locked screw plate construct. For example, in diaphyseal or metadiaphyseal areas, any fracture distraction at the time of reduction or fracture resorption during healing will be held rigidly by such constructs and may potentially result in delayed union or nonunion. In this situation, no load sharing can occur with locked screws on either side of a fracture. If the fracture is repetitively loaded, the plate eventually may fracture or fixation may be lost. Because of these concerns and the additional cost of a locking plate compared with an equivalent but nonlocking plate, locking plates probably should be used selectively for fractures that have demonstrated high failure rates with conventional plating techniques.

Another disadvantage of current locking plate design is the inability of the surgeon to alter the angle of the screw within the hole and still achieve a locked screw. The use of certain screw holes in the plate potentially could be blocked by lag screws placed for articular reduction, unique fracture geometry, anatomic variations, or implanted components of a joint arthroplasty. Any attempt to contour locked plates could potentially distort

Figure 5  A, Anteroposterior radiograph of a comminuted tibial plateau fracture. B, Postoperative radiograph after internal fixation with a locked tibial plate. C, Healed fracture at 1-year follow-up. (Courtesy of Synthes, Paoli, PA.)
the screw holes and adversely affect screw purchase. Newer developments have focused on plates with so-called polyaxial locking screws to address this concern (eg, VersaLock, DePuy, Warsaw, IN). A bushing inside the plate hole expands because of hoop stresses as the screw is tightened, thereby allowing freedom of screw angulation and the mechanical benefits of a locking screw. Clinical data on this technology, however, are currently lacking.

When using locking plates, hardware removal may be more difficult, especially if locked screws become cold-welded to the plate. Current systems offer torque-limiting screwdrivers that may minimize this concern.

**Clinical Experience**

Most published clinical studies of locking plate fixation have focused on the results of the LISS plate in fractures of the distal femur and proximal tibia. This device is an externally targeted plate designed for submuscular, extraperiosteal application, with all screws locking to the plate. In one prospective trial that encompassed nine European trauma centers, 112 patients with 116 fractures of the distal femur were treated. Ninety-six patients with 99 fractures of the distal femur and proximal tibia (45 patients) were treated with the LISS plate. Of the 16 open fractures, there was one infection. One patient required bone grafting to achieve union, and no varus collapse or loss of proximal fixation was reported. Six of the 46 fractures (13%) had malalignment ≥5°. Gosling et al and Ertl and Smith reported encouraging results using lateral locked plating as an alternative to double plating in bicortical tibial plateau fractures.

An obvious interdependence has developed between locked internal fixation technology and minimally invasive techniques of plate application. Although impressive union rates have been reported, this may be the result of improved soft-tissue handling techniques, a favorable biologic environment, and the improved mechanical stability provided by locking plate technology. Additionally, it appears that unicortical fixation is adequate to achieve union; in the absence of errors in surgical technique, reported rates of fixation failure are very low. When percutaneous techniques are used, malalignments are more common, and the surgeries remain technically demanding. With increased experience and the development of new techniques to improve the accuracy of closed reduction, the frequency of such malunions should decrease. The long-term clinical significance of this malalignment remains unknown.

**Summary**

Initial clinical data demonstrate excellent union rates, low rates of fixation failure, and few complications with the use of locking plates for internal fixation of fractures, particularly periarticular fractures. Locking plate technology will undoubtedly proliferate for fractures in other anatomic locations. Hybrid plates offering the versatility of choosing either a locked or unlocked screw will probably enjoy widespread use. The clinical success of these implants is likely the result of the improved biologic environment provided by minimally invasive plate insertion as well as the stable mechanical environment. As with all new technology, caution is warranted. Because these implants are used for difficult fractures, complications both old (eg, malalignment, infection) and new (eg, difficult hardware removal, misplaced screws, pullout) will occur. When such plates are inserted percutaneously, malalignment is common. Further clinical and biomechanical research on locking plate technology is needed to fully define its place alongside existing technology in orthopaedic trauma.
References

29. Cole PA, Kregor PJ: Prospective clinical trial of the less invasive stabilization system (LISS) for proximal tibia fractures, in Orthopaedic Trauma Association 18th Annual Meeting Final Program. Rosemont, IL: Orthopaedic Trauma Association, 2000, p 344.
