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Locked Plating: Biomechanics and Biology

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Summary: Since the early ideas of internal fixation, many different concepts and techniques have been developed for the use in fracture surgery. Each technique has been welcomed by many with excitement while others have suggested caution, locked plating is no exception. Since its advent over 15 years ago many have viewed this as a violation of the strict AO principles of anatomic reduction and rigid fixation. Others have looked at it as an extension of the blade plate (single locked plate), that is, an "internal external fixator." This initial paper will deal with the biomechanics and biology of locked plating as compared with conventional plating. The following paper will suggest some of the clinical indications and the rationale for use of locked plating. In reviewing biomechanical studies, the surgeon must be clear on the model that is used including the number of screws on each side of the fracture, how close the screws are to the fracture site, the length of the plate, how close the plate is to the bone, the material of the plate and the screws, unicortical or bicortical screws, the density of the bone, and the stability of the fracture. Furthermore, the surgeon must understand that more stability does not always equal better healing. Although fractures require a 2% to 10% strain rate to heal, the optimal biomechanics for fracture healing is unknown. Too rigid of fixation can delay healing. A strain rate of >10% may not allow bone to form at the fracture site. Locked plating has different biomechanics in axial loading, bending, and torsion. Biologically, locked plating preserves the blood supply by preventing necrosis under the plate (no compression between the plate and the bone) and allows a more percutaneous insertion. Although locked plating is a useful tool, indiscriminate use will cause the surgeon to lose the fracture-healing race and cause construct failure. **Key Words:** Conventional plating—Locked plating—Biomechanics of plating—Biology of plating—Axial load—Bending load—Torsional load—Hardware failure—Fracture stability—Primary bone healing—Secondary bone healing—Strain in fracture healing.

EVOLUTION

The idea of fixed angle stability or angular stability in orthopaedic fracture management first started with the advent of blade plates in the 1950s. These first plates were designed to address fractures of the proximal and distal femur where physiologic stresses are high. The one-piece design with a U shaped profile and 130 or 95 degree fixed angle allowed use in these areas. These plates provided stable fixation but many considered their use demanding and technically challenging requiring precise 3-dimensional alignment and careful preoperative planning. Another technology that modern locked plating was developed from was the Schuhli device.[8,9] This consisted of a 3-pronged nut and washer construct. This construct functioned to lock a cortical screw to a plate to enhance stability thus creating a fixed angle device. The nut would engage the screw at 90-degree angles locking to the plate thus elevating the plate from the bone and in theory prevent periosteal compromise. Another early locking construct was the Polish ZESPOL system.[16] All of these concepts provided a rigid construct at fixed angles. The first locked plate introduced for mass use was the Point Contact fixator (PC-Fix I, Synthes, Paoli, PA). It was initially developed for use in forearm fractures.[7] This system used limited bone-plate contact and unicortical/self tapping screws with a narrow plate

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design. By locking the screws into the plate, an angular and axial stable construct was created. This was followed by the PC-Fix II. Both of these preceded the Less Invasive Stabilization System, or LISS plate (Synthes). Its advent introduced a plate with anatomic contouring especially applicable for the distal femur and proximal tibia.[2,5,17] Fractures involving the distal shaft, supracondylar region, and meta-diaphyseal areas of the femur could be addressed. This system could also meet the requirements of fixed angle stability, but also with atraumatic percutaneous insertion. This system followed the evolution of locking technology, but also used a jig to help with percutaneous insertion and biologic plating. Thus the dogma of type of implant used switched to minimally invasive plate osteosynthesis, or MIPO, which respected the soft tissue envelope while addressing rigid fixation.[4,11] The LISS application was then expanded to include periprosthetic fractures with prior inserted hardware, for example, Total joint arthroplasty.[1,10] By using unilateral plating with unicortical screws around previous hardware reliable and stable fixation could be achieved especially in osteoporotic bone that typically surrounds this situation. Still with this tool, the reduction of articular segments had to be carried out with independent lag screws before insertion of a LISS plate (bridging technique). Development of plates where a lag screw or a locked screw could be used [Locking Compression plate (LCP)].[18] This plate functioned as a hybrid technology utilizing both original AO principles of compression plate with locking capability. Lag screw insertion could then take place through the plate achieving anatomic reduction followed by locking of screws to the plate. Now with proper use of "combi" holes both concepts can be blended using initially lag screws followed by either unicortical or bicortical locked screws for neutralization. Further evolution has developed multi directional locked screws. The beneficial biomechanics of angled locked screws needs further evaluation but may be very plate and locking mechanism dependent.

BIOMECHANICS

Before a discussion on biomechanics, the surgeon must be familiar the concept of strain and how this affects healing fractures. Perren first demonstrated how under different strain environments different types of tissue would form stating that "tissue cannot be produced under strain conditions which exceed the elongation at time of tissue rupture."[12] Strain is defined as relative change in fracture gap divided by fracture gap. Thus, gap strain is reduced by factors that decrease motion or increase fracture gap. Fracture comminution or poor reduction are both situations that increase gap thus lower strain. In addition, compression and/or rigid fixation reduce motion thus lowering strain. When conditions of strain less than 2% exist than fracture, healing will proceed by primary means without callus formation. New bone will form by cutting cones directly as in compression/neutralization plating. If 2% to 10% strain occurs than secondary bone, healing will occur with callus formation. Examples of this include: nonoperative treatment, external fixators, intramedullary nails, and locked plates. In conditions of greater than 10% strain, only granulation tissue arises leading to fibrous unions.

AXIAL LOADING

Conventional plating relies on a completely different set of principles to obtain stability in axial loading compared with locked plating. The function of the standard plate and screws depends on the fracture requirements (neutralization plate–load-sharing, antiglide plate–load-bearing). Conventional plates loaded axially resist the force via the shear stress between the plate and the bone. The typical torque applied to 3.5 mm screws is between 3 to 5 Nm (Newton meter) that resist axial loads as small as 500 N (~125 lbs.).[3] The screw with the greatest amount of force bears the greatest load. The strength of the plate screw construct after application of an axial load greater than the frictional force (i.e., the screw torque within the plate) depends on the axial stiffness of the single screw farthest from the fracture site (~1200 N for a typical 3.5 mm screw).[3] This assumes that the compressive strength of cortical bone at the fracture site is greater than 1200N (that is not the case when comminution at the fracture site exists or osteoporosis is present). As long as the patient load does not exceed the frictional force of the plate to the bone and the axial stiffness of the screw or cortical bone at the fracture site, the construct is stable enough to allow healing (Fig. 1). In compression plating under ideal circumstances the friction between bone/plate achieved by plate contouring and screw placement/purchase will result in forces creating minimal motion at the fracture site (LC-DCP). This can only happen if the bone/screw purchase plus the coefficient of friction between the plate and the bone creates enough frictional force to withstand loading (no motion), essentially creating a fixed angle construct. The screw torque needed to gain sufficient purchase can be increased by increasing screw contact area to bone or plate/screw relationships.[3] Although possible in fractures with good bone quality, osteoporosis or pathologic bone present different circumstances. Poor bone does allow bicortical purchase but this stability might not be enough

Conventional Plate Fixation Axial Load

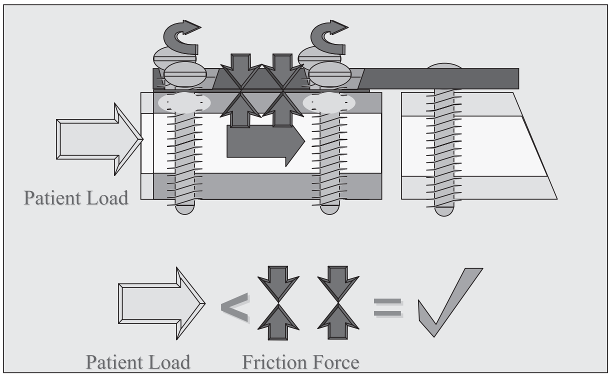

FIG. 1. Conventional plating with a fracture gap relies on the frictional force between the plate and the bone to resist axial load.

Locked Plate and Screw Fixation Axial Load

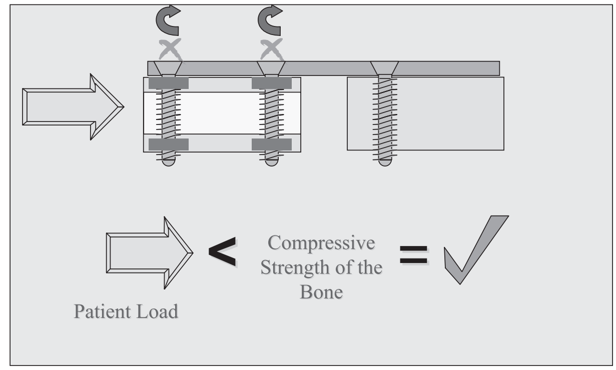

FIG. 3. Locked plating relies on the compressive strength of bone to resist the axial load.

to allow healing. In osteoporosis or comminuted fractures, the frictional force may not be greater then the axial load by either failure to achieve sufficient torque on the screws or excessive motion at the fracture, respectively, which would could lead to hardware failure (Fig. 2).

In locked plating, the screws lock into the plate and do not rely on the frictional force between the plate and the bone but the compressive strength of bone. A locked plate converts an axial load shear force into a compressive stress at the screw bone interface. The strength of fixation is equal to the sum of the entire screw bone interface of all the screws as opposed to a single screw as in unlocked screws (Fig. 3). Bicortical screws will give a greater interface therefore greater stability. Whether this makes the construct too stable depends on the material of the plate, the positions of the screws, and the number of screws. The failure of a locked plate during an axial load is the failure of the compressive strength of bone over the area of all the screws in the construct.

BENDING

Bending tests require a fracture gap greater than zero. Otherwise, the resistance to bending is controlled by the compressive strength of bone on both sides of the fracture site either with the plate in compression or tension. When the conventional plate is placed on the tension side of the bone with a fracture gap greater than zero, the highest shear stress occurs at the screw at the end of the plate farthest from the fracture site. If the plate is placed on the compression side, the highest stress occurs at the screws closest to the fracture site. The force to failure is the force required to overcome the shear stress of bone times the surface area between the bone and the single screw. Once that screw begins to fail the next screw begins to fail and this continues sequentially (Fig. 4). Under bending forces, screw/plate toggle occurs with subsequent failure if loads are increased. A high-shear force that exceeds strength of cortical bone can cause failure in bending with bone absorption and screw

Standard versus Locked Loading Axial Load

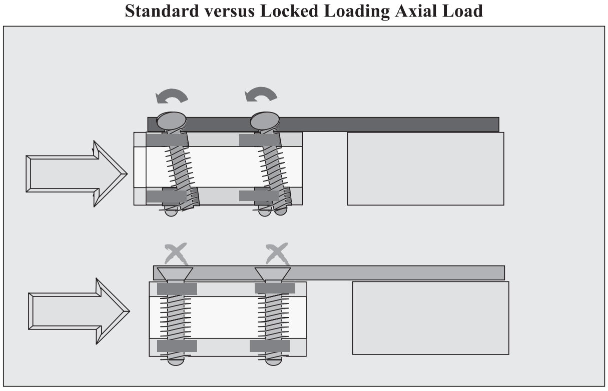

FIG. 2. If the frictional force in conventional plating is exceeded by the axial load, than the screws will angle and hardware failure occurs.

Conventional Plate Bending Load

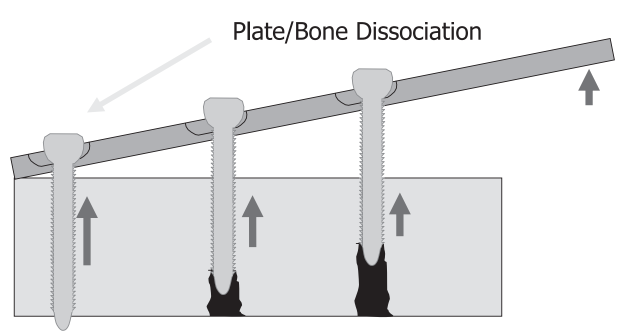

FIG. 4. Failure of conventional plating with a bending force and the plate on the compression side stresses the screw closest to the fracture site first with subsequent failure of the other screws.

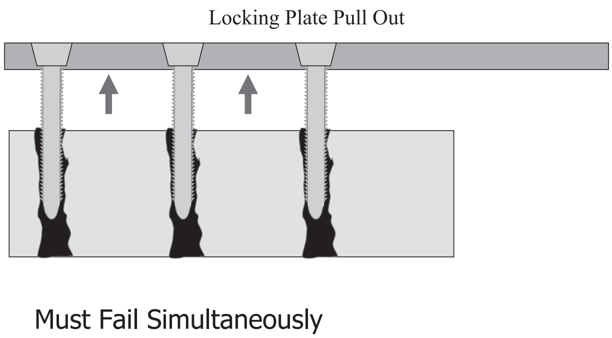

FIG. 5. Failure of locked plating with pure pullout of the screws is rare compared with Figure 6 but still requires all screws to fail simultaneously as opposed to conventional plating shown in Figure 4.

loosening leading to motion at the fracture site. With motion, high gap strains exist that lead to no bony healing.[6,15] This shear takes advantage of the weakest link in the plate/bone/screw relationship, that is, screw/bone interface.

In locked plating, because of the screws lock into the plate, they must all either fail simultaneously as the plate backs directly out (Fig. 5) or more likely a preferential failure of the screw bone interface. This second and more common mode of failure involves bone failure both in compression and shear with the greatest screw displacement either next to the fracture site or at the end of the plate depending on whether the plate was placed on the compression or tension side (Fig. 6). In either mode of failure, because all of the screws are part of the construct, the stability of the construct is significantly greater than with conventional plating again assuming a gap at the fracture site. Locking constructs give another "cortex" with the screw locking into the plate. In this situation, failure will only occur if perpendicular forces to the plate overcome the compressive forces of bone surrounding all the screws and the construct moves as one unit, that is, the locking screws fails to neutralize bending loads. Even in osteoporotic bone, this failure is less likely to occur than one screw failing in the conventional plating. Clinically the purchase of the locked screws in the bone can be so strong that failure could occur by the plate displacing from the bone and taking a large section of bone still attached to the locked screws. In essence the fixation strength of locked plating equals all bone/screw interfaces, thus providing a very rigid construct.[15] Locking pullout strength can further be increased by placing screws in divergent patterns as opposed to traditional parallel orientations. This design feature has been added to many plates available to surgeons however, independent biomechanical analyses for these newer designs are not available at this time.

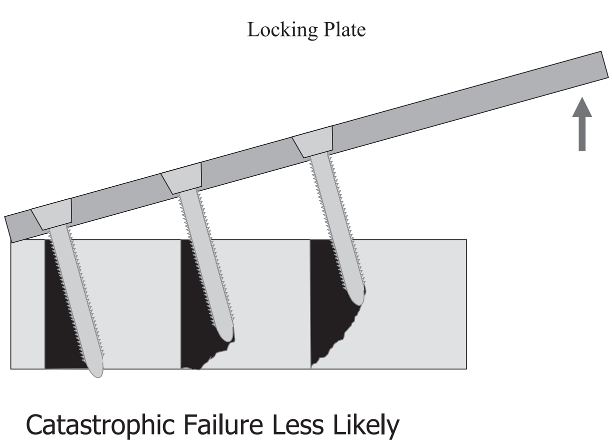

FIG. 6. Failure of locked plating with a bending force causes compression of bone as well as shear between the screws and the bone. Again the strength of the construct includes the strength of the interface between all the screws and the bone as opposed to just the interface of the screw closest to the fracture gap as in conventional plating.

TORSION

The torsional stability of a construct is more dependent on the number of screws rather than whether the screws are locked or conventional. Given this, a slight motion is possible between the screw head and the plate in the conventional plating depending on the torque used to place the screw, the size of the screw head, the design of the plate, and the material used in conventional screws. This may lead to a little greater instability compared with locked screws; however, this is probably not clinically relevant.

BIOLOGY

In managing fractures, a surgeon must be familiar with management of the soft tissue. Typically, bony injury associated with high-energy trauma causes a significant soft tissue injury that may compromise the options available to the surgeon. The old notion of stripping the soft tissue to obtain anatomic reduction of each piece has lead to an increase in infection rates and delayed healing of the fracture. Anatomic alignment of the bone is required not anatomic alignment of each piece in a shaft fracture. Anatomic alignment of each piece may be required in articular fractures. In either case, careful soft tissue handling is required and enough exposure is required to prevent a malunion. With conventional compression plating, multiple changes occur underneath the plate while fixed to bone. Damage to periosteal blood supply with compression has been demonstrated as has stress shielding from the plate.[14] These findings have led to the development of the Limited Contact Dynamic compression plates (LC-DCP) that reduces contact area by 50% but still requires the plate bone interface to give stability in comminuted fracture gaps.[13] Also, bicortical drilling has been shown to damage intramedullary/endosteal blood supply. Both of these problems have been addressed by unicortical locked plating. Unicortical screws are less traumatic to the intramedullary blood supply and by not having to rely on friction contact between plate and the bone, less periosteal disruption occur therefore enhancing the blood supply to the fracture. As mentioned, the unicortical screw will have less surface area than the bicortical screw therefore there will be less stability. Whether this decrease in stability is relevant depends on the clinical situation. By not causing local necrosis under the plate, locked plating prevents stress-shielding allowing hardware removal with less of a risk of refracture.

With the development of biologic plating, the idea of less traumatic methods for insertion of the plate has been developed. Submuscular plate placement avoids extensive periosteal stripping and allows the incisional sites to be located away from the fracture area thus avoiding the zone of injury.[4] However, the surgeon must always wait for soft tissue healing before making an incision. Proximal tibial fractures with a proximal insertion site can have disastrous soft tissue complications because the zone of injury is within the insertion site.[19] The use of target devices and threaded locking guides facilitates ease in placement with regards to good soft tissue handling techniques. Screws can then be placed by small stab incisions as opposed to extensile exposures. A surgeon must be careful because targeting devices can lead to misplaced screws that miss the bone since the surgeon loses the feel of traditional screw purchase as the screws lock tightly into the plate. This occurs frequently in the proximal femur where the screws skive one cortex without any real purchase in bone.

The lack of intimate contact between plate and bone has led locking plates to be called "internal external fixators" taking advantage of the concepts of external fixation. In comparison to external fixators, internal fixators offer more stability by being closer to the bone. Preserving the periosteal blood supply theoretically prevents stress shielding, reduces infection risks, and promotes fracture consolidation.

SUMMARY

Conventional plates rely on different mechanical principles to obtain fracture stability as compared with locked plating. Conventional plating relies on the friction between the plate and the bone as well as a minimal fracture gap to withstand deforming loads and eventually obtain union. Locked plates are internal fixators increasing the stability of the fracture by creating an additional cortex (the plate) and locking the screws into the plate thus distributing the deforming loads to all the screws equally as opposed to those screws closest and furthest from the fracture site. This may be particularly important in situations where bone quality is poor or there is significant segmental comminution at the fracture site.

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