A REVIEW PAPER

Has Locked Plating Completely Replaced Conventional Plating?

Michael J. Gardner, MD, David L. Helfet, MD, and Dean G. Lorich, MD

Abstract

The 2 main approaches to fracture plate fixation—compression plating and internal splinting—result in differing biomechanics and subsequent healing response patterns. A number of advantages to using the newer internal fixators have been described, but there are still several indications for traditional compression plating.

Over the last 2 decades, an increasing understanding of bone healing biology and the biomechanics of fracture fixation has led to a significant evolution in plating techniques. A new implant, the internal fixator, has emerged in parallel with new principles and techniques in fracture fixation. The focus of "biological fixation" is on the ideal physiologic environment to allow fracture healing, rather than on rigid compression fixation and absolute stability. Screws with threads on the undersurface of the heads form a fixed-angle construct with the plate and function as bolts anchored into the bone, relieving the friction force at the bone-implant interface, which is a critical component of compression plating. Indirect reduction with minimal or no fracture exposure, coupled with long plates and fewer strategically positioned, well-spaced locked screws spanning comminuted fragments, contributes to stable flexible fixation and results in indirect fracture healing by callus formation. Avoiding soft-tissue dissection and vascular disruption at the fracture site may also decrease the risk of necrosis and infection.[1-3]

There are generally 2 main principles of fracture plate fixation: compression plating and internal splinting. Each technique results in different biomechanics and subsequent healing response patterns. Although theoretical and clinical advantages to using newer internal fixator implants have been described,[3-11] several definite indications for traditional compression plating still exist.

Biomechanics

Compression Plating

Conventional plate fixation, as we know it today, was popularized by the AO group in the mid–20th century and based on the work of Robert Danis.[12] Compression techniques restore precise anatomy, generally through a wide surgical exposure. Fracture fragments are individually exposed and interdigitated, likely leading to a degree of iatrogenic soft-tissue trauma. Subsequent plate fixation, using either an external compression device or the dynamic compression properties of the plate, relies on preloading of several interfaces in the construct.[13-15] As screws are tightened, forces are generated at the screw thread-bone junction, between the fracture fragments, and most importantly, between the plate and the bone.[16,17] This compressive preload acts to initially reduce fracture motion to nearly zero.[16,17]

Traditional plating demonstrates characteristic biomechanical behavior under cyclic load.[18,19] Bending of a rigidly fixed construct results in shear stresses between the plate and bone, provided that the pull-out strength of the screws is not overcome.[18,20] The conventional screw head is free to toggle within the plate, so the eccentric lever arm created by the pull of the plate on the screw leads to anchorage of the tip of the screw in the far cortex and toggle in the near cortex (Figure 1).[18] A slightly oval shaped hole is created as the screw radially compacts cortical and cancellous bone. Compaction continues until the remaining rim of bone is strong enough to resist further displacement, and an increase in stiffness results. A new baseline position is established, at which cycling occurs,

---

Dr. Gardner is Senior Resident, Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, New York. Dr. Helfet is Professor of Orthopaedic Surgery, Weill Medical College of Cornell University, and Director of the Combined Orthopaedic Trauma Service at both the Hospital for Special Surgery and New York–Presbyterian Hospital. Dr. Lorich is Associate Director of the Orthopaedic Trauma Service, Hospital for Special Surgery and New York–Presbyterian Hospital, Assistant Professor of Orthopaedic Surgery, Weill Medical College of Cornell University, Adjunct Assistant Professor at Albert Einstein School of Medicine, and with the Orthopaedic Trauma Service, Hospital for Special Surgery, New York, New York.

Please address all correspondence to Michael J. Gardner, MD, Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021 (tel, 212-606-1466; Fax, 212-774-2779).

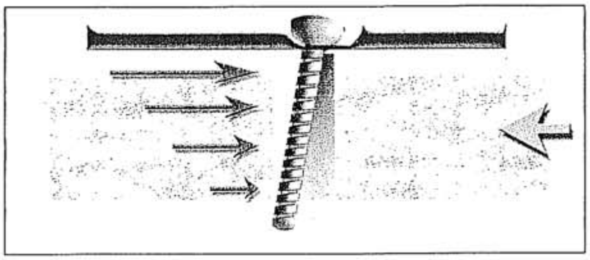

Figure 1. If a screw resists pull-out failure, bending forces are converted to shear stresses. The eccentric lever arm results in a greater force at the proximal cortex, where cutout is initiated.

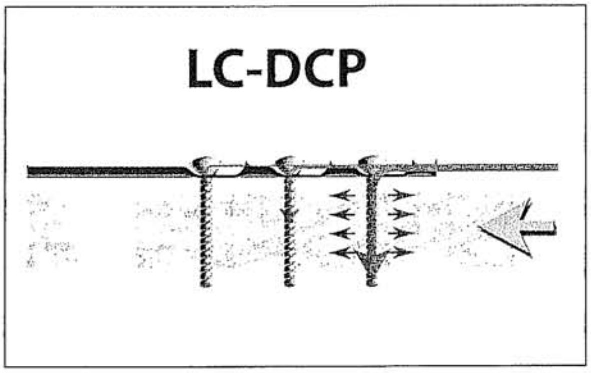

Figure 2. Because a conventional screw head is allowed to toggle during loading, energy is dissipated at the bone-screw interface farthest from the fracture. Energy is concentrated at this level, shielding additional screws from load initially.

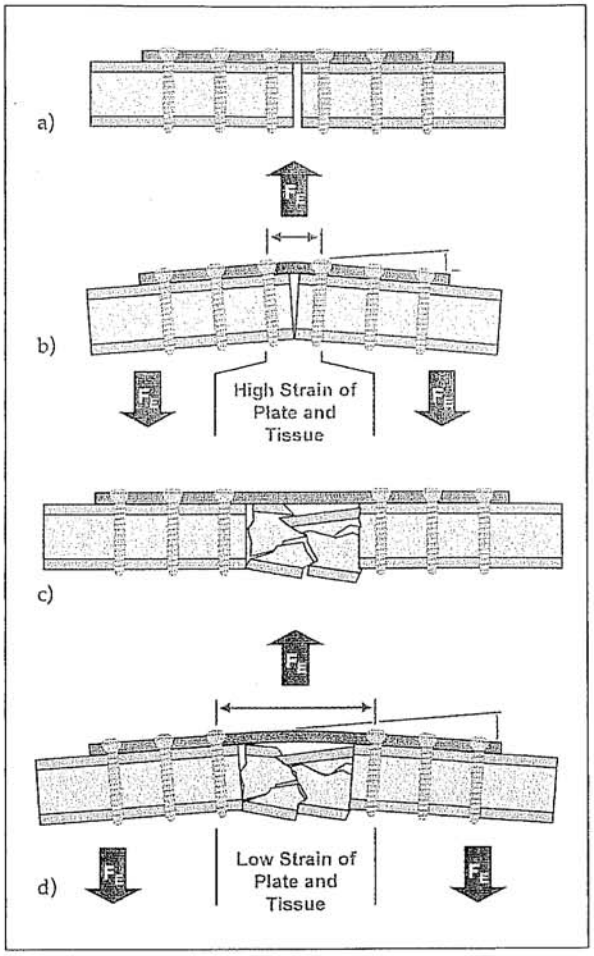

Figure 3. Stability using internal fixators is maximized by spanning comminuted segments. **(A,B)** A short span that is stressed deforms over a short length, leading to high fracture and implant strain. **(C,D)** When the spanning segment is longer, the same force applied leads to a similar angular deformation, but the strain is distributed over a greater plate length, leading to lower implant strain and a higher resistance to fatigue. Reprinted from *Injury,* vol. 34 (suppl 2); Gautier E, Sommer C. Guidelines for the clinical application of the LCP, B63-76. Copyright 2003, with permission from Elsevier.

although the overall construct becomes slightly plastically deformed.[19,21,22] New microfractures accumulate as cycling progresses until the bone can no longer resist the load, resulting in further displacement and a drop in stiffness.

It is also important to consider the effect of load on the entire construct. As load is applied to the end of the bone, it is transferred down the bone and is first concentrated at the screw most distal from the fracture.[4,19] Subcatastrophic failure and deformation eventually occur, and energy is dissipated within the bone. This initially shields the "downstream" screws from load, until failure progresses and load is propagated to the remaining screws (Figure 2).[19,23] Isolation of load at this single interface may overcome the cutout resistance of the bone, leading to subcatastrophic failure and transfer of the load to the next screw.

Locked Plating

"Biological fixation" and the use of locked plates attempt to create a biomechanical environment entirely different from that obtained with compression plating. Fracture surfaces are not compressed, and a bridging fixator allows a small amount of elastic motion at the fracture site. The magnitude of displacement depends on the load applied and the stiffness of the device[20,24] and also determines the tissue differentiation at the fracture site.[25] To maximize implant stability under flexible fixation, long plates with a low screw density should be used to increase the working length and disperse the bending forces.[3,26] Empirically, a plate length of greater than 3 times the fracture length in comminuted fractures and greater than 8 to 10 times the fracture length in simple fractures has been recommended.[26,27] Screw-to-plate-hole ratios of less than 0.5 create a long lever arm and decrease the bending loads on the distal screws.[28] In addition, a span of at least 2 to 3 screw holes should be left open over the fracture to decrease stress concentration (Figures 3 and 4).[27,29]

Regarding the implant-bone interface, the screw-plate locking mechanism acts as a surrogate cortex that is not prone to cutout because, in locking con-

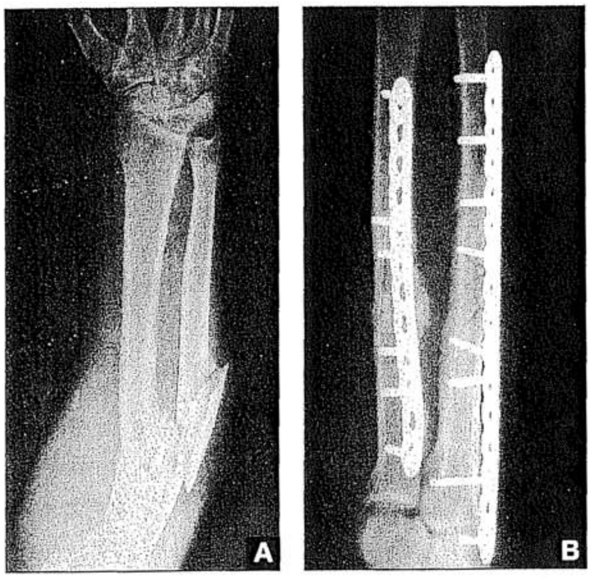

Figure 4. (A) Comminuted both-bones forearm fracture in a 38-year-old man. **(B)** Six months after treatment with internal fixators, the fractures have healed in good alignment with abundant callus formation, particularly in the radius. Note the empty screw holes bridging the fracture, the long plate span, and the low screw density.

structs, the screws are angularly stable. As load is transferred down the construct, this prevents load concentration at a single screw; instead, load is distributed more evenly to each screw and bone-screw interface (Figure 5). This may be particularly important in regions where obtaining sufficient screw purchase can be difficult, such as in metaphyseal osteoporotic bone.[4] In addition, the function of the plate and screw as a cortex allows unicortical screw placement in the bone, and screws may be inserted in a minimally invasive fashion without direct measurement.[30, 31]

Biological Aspects

Compression Plating

The method of fixation and the relative stability achieved directly affect the path a fracture takes to heal. When motion is completely abolished between fracture fragments, no callus forms.[16,17] This has been termed direct healing, whereby osteones directly bridge the fracture gap, forming regenerate bone, and the fracture heals by remodeling.[32,33] However, the compressive preloading of the plate and bone necessary to attain this absolute rigidity reduces periosteal blood flow to the cortex and may lead to resorption of cortical bone beneath the plate owing to necrosis.[32,34] Resorption may lead to decreased stability as the friction force deteriorates. Impaired vascularity and instability may further lead to a greater risk of infection or failure of healing.[8,11]

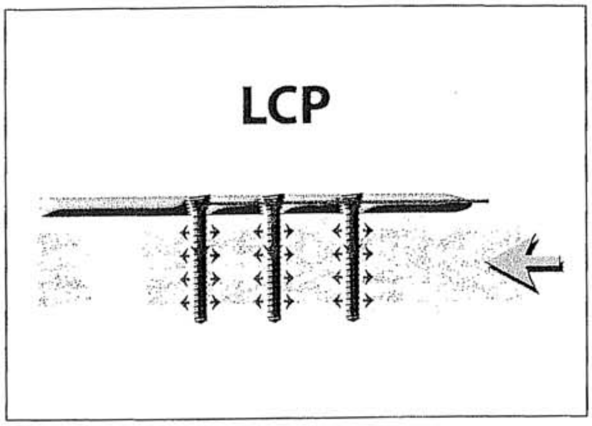

Figure 5. In internal fixators, the angularly stable screws prevent load concentration at a single bone-screw interface.

Locked Plating

Because of the angular and axial stability of the screw-plate interface in a locked device, friction is not required to secure the plate to the bone, as in conventional plating. Rather, the plate may be kept a small distance off the bone, minimizing periosteal vascular damage. Fracture fragments may be purely splinted without compression, resulting in flexible elastic fixation and stimulation of callus formation.[32,35] This leads to a different pathway of healing, indirect healing, which involves sequential tissue differentiation[36] and is similar to that seen with intramedullary nailing or cast immobilization.

Fracture fragments may be purely splinted without compression, resulting in flexible elastic fixation and stimulation of callus formation.

The amount of fracture displacement relative to the fracture gap has been described in the "strain theory" of fracture healing.[20] Each type of tissue tolerates a certain amount of strain; more rigid tissues tolerate less strain (eg, woven bone tolerates up to 10% strain, whereas granulation tissue tolerates up to 100% strain).[16,25] Above these thresholds, fibrous tissue differentiation occurs and the bone forming process is impaired. Within a range of tolerable strain, fracture ends are resorbed, reducing the strain and leading to differentiation of callus and woven bone.[32] Flexible fixation results in resorption of bone and widening of each fracture gap, enough to reduce strain and allow differentiation of bone-forming precursor tissues.[20] This is the reason that flexible fixation with locked plating is ideally suited for indirect reduction of highly comminuted fractures, where multiple fracture lines share the overall displacement, reducing the strain at

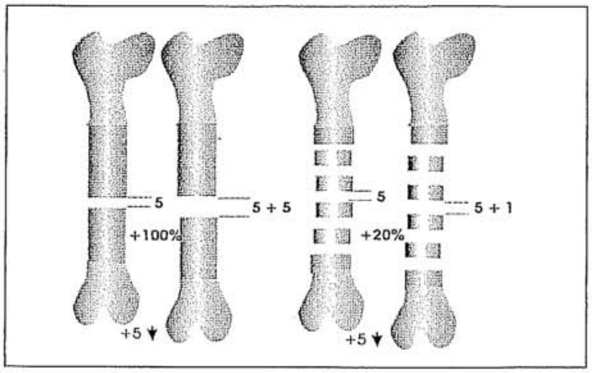

Figure 6. Comminuted diaphyseal fractures are ideally suited to bridging fixed-angle implants. The total load is dispersed among the individual multiple fractures lines, ensuring a strain level compatible with callus formation is present at each fracture. From Perren SM. Evolution of the internal fixation of long bone fractures. *J Bone Joint Surg Br.* 2002:84(8);1093-110. With Permission.

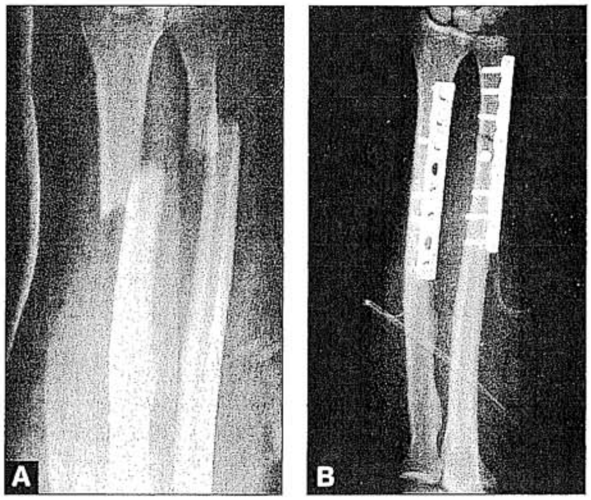

Figure 7. For simple transverse diaphyseal fractures, such as in the forearm **(A)**, compression plating with fixation in 6 cortices on each side of the fracture is indicated **(B)**.

each gap to within bone-forming thresholds (Figure 6).

To obtain indirect healing using flexible fixation, 2 conditions are necessary: (1) stable elastic fixation is established (ie, deformation under load is reversible), while small fracture gaps are avoided, thereby minimizing situations of high localized implant and fracture strain; and (2) minimal surgical dissection and vascular disruption occur at the fracture site (ie, the plate must not be pressed to the bone).[1,2,32]

Clinical Indications

The techniques of indirect reduction, fracture-spanning fixation, and locked plating give surgeons a new option for treating many fractures. Fractures without significant soft-tissue stripping or vascular damage best tolerate the relative fragment motion necessary to stimulate indirect fracture healing.[20] Closed comminuted diaphyseal or metaphyseal fractures are particularly suited to bridging fixation using locked plates. As long as the limb is aligned with respect to axis and rotation and is reduced to its appropriate length, anatomic fracture fragment reduction is not necessary. Meta-epiphyseal fractures with little periarticular bone stock for fixation may benefit from an internal fixator. Fractures that occur around an arthroplasty prosthetic stem or an intramedullary nail may be treated with an internal fixator device. An internal fixator can also be considered when it is desirable to convert external fixation of a long bone fracture to internal fixation, but the delay precludes intramedullary nailing because of medullary colonization (approximately 14 days).[37] Lastly, with the increasing size of the elderly population and incidence of osteoporosis, fixed-angle constructs may lead to improved stability in poor quality bone,[4] and locked plating may be used for any extra-articular fracture pattern.[38]

However, conventional compression plating is still indicated in specific situations (Table). For simple transverse or short oblique diaphyseal fractures without significant comminution, compression plating is preferable when adequate cortical contact can be obtained with minimal manipulation (Figure 7).[38] In this situation, when direct open exposure of a diaphyseal fracture is being considered, it is important to assess the surgical status of any traumatic soft-tissue injury. Studies have demonstrated that internal fixators may be adequate for these single diaphyseal fractures,[11] but the resulting high strain due to the concentration of displacement at a single fracture gap makes adequate stabilization with a fracture-spanning device difficult. Articular surfaces require anatomic reduction without gaps or step-offs to minimize the risk of developing posttraumatic arthrosis; thus, all intra-articular fractures should be directly reduced and stabilized using compression techniques with lag screws through or outside the plate.[37]

Articular surfaces require anatomic reduction without gaps or step-offs to minimize the risk of developing post-traumatic arthrosis

Finally, all nonunions and most delayed unions require compression plating with lag screws to improve the mechanical stability and stimulate healing. In these situations, the surgical dissection necessary to débride the nonunion and mobilize the fracture fragments acts to devascularize the fracture environment, and anatomic reduction and rigid compression plating should follow.

Combination Techniques

Several internal fixator devices contain "combination" screw holes that allow either compression or locked

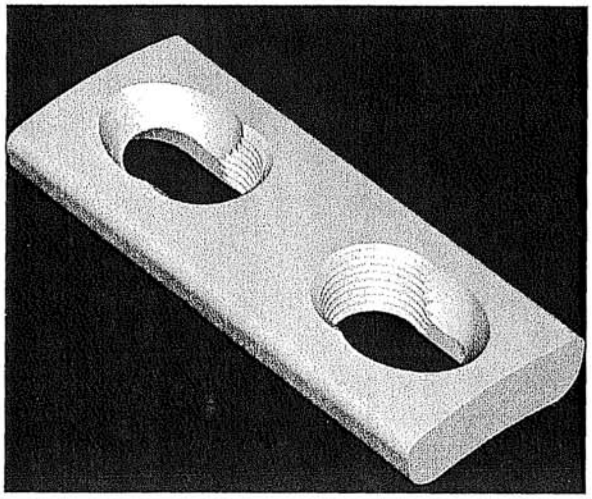

Figure 8. Schematic demonstrating the combination hole, allowing conventional or locked screws to be placed in the same implant. Reprinted from *Injury,* vol. 34(suppl 2), Frigg R. Development of the locking compression plate, B6-10. Copyright 2003, with permission from Elsevier.

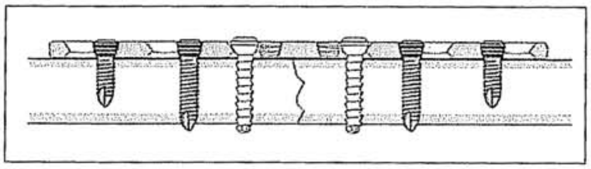

Figure 9. In osteoporotic bone, the surgeon may combine techniques within 1 fracture fragment. The fracture is initially compressed with conventional screws, and supported by subsequent locking screws. Reprinted from *Injury*, vol. 34(suppl 2), Wagner M. et al. General principles for the clinical use of the LCP, SB31-42. Copyright 2003, with permission from Elsevier.

screws to be placed within the same implant (Figure 8). While this allows greater flexibility in deciding between biomechanical principles, the surgeon must carefully consider which situations are suitable for using mixed techniques. The biomechanics of the 2 principles are generally thought to be mutually exclusive; however, in some situations a combination may be applicable: (1) For a segmental diaphyseal fracture with 2 distinct regional fracture configurations (comminuted and simple), a long plate spanning both fractures may be used, compressing the simple fracture and bridging and splinting the comminuted segment. (2) For intra-articular fractures with metaphyseal extension, articular fragments may be anatomically reconstructed and compressed by lag screws through a plate, followed by bridging of the comminuted metaphysis by placing locked screws in the metadiaphyseal segment. (3) When residual malalignment following indirect reduction remains, a compression screw may be provisionally inserted to both reduce the plate to the bone and correct axial alignment at the fracture site. Ideally this should be replaced with a locked screw if true flexible fixation is to be obtained.

Using both conventional and locked screws in the same fracture fragment should be done with caution.

Using both conventional and locked screws in the same fracture fragment should be done with caution. Compressing the plate to the bone negates the vascular preservation principle of the locked screws, and using the locked screws does not add to the friction fit of the compression screws. The hazards of applying principles of both rigid and flexible fixation to the same fracture have been well demonstrated by Krettek and colleagues.[39] In a study of tibial shaft fractures, patients treated with external fixation plus a lag screw had twice the refracture rate and required bone grafting for nonunion more often compared with those treated with external fixation alone.[39] Nevertheless, the one clinical situation in which this may be useful is in patients with poor bone quality.[38]

TABLE. INDICATIONS FOR COMPRESSION OR BRIDGING INTERNAL FIXATOR TECHNIQUES*

Specific indications for the different techniques				
	Compression	Bridging	Combination	
Simple diaphyseal fractures	+			
Simple metaphyseal fractures	+			
Multifragmentary diaphyseal fractures		+		No compression!
Multifragmentary metaphyseal fractures		+		No compression!
Osteotomies	+	+		
Articular fractures	+ No bridging!			
Articular fractures with multiligamentary meta-or diaphyseal fractures			+	
Segmental fractures with two different fracture patterns			+	

*Reprinted from *Injury,* vol. 34(suppl 2), Wagner M. General principles for the clinical use of the LCP, pp SB31-42, Copyright 2003, with permission from Elsevier.

Initially compression screws are placed in each segment to achieve a friction fit and compress the fragments. Subsequently, locking screws may be used in place of the remaining conventional screws (Figure 9). These locking screws function to support the reduction and compression, without adding additional compression and risking implant cutout by overtightening. Furthermore, the angular stability may improve the overall strength of the construct by minimizing forces at the screw-bone interface. The biomechanics of this construct have not been proven, and it is generally considered that combining principles in the same fracture fragment does not take full advantage of either principle.[40]

Conclusions

Biological fixation is a new concept in fracture surgery that involves using indirect reduction and internal fixators, which results in stable flexible fixation, preserved vascularity, and timely bone healing. These technologies and techniques continue to evolve. Early biomechanical, animal, and clinical studies indicate that handling is not overly difficult, healing is reliable, and resistance to infection may be enhanced.[1,9,27] Recommendations currently are that indirect surgical approaches and reductions,[7,41] followed by locked plating, be performed whenever technically feasible.[26] Specific indications include comminuted diaphyseal and metaphyseal fractures and fractures in osteoporotic bone.

Locked plating has not completely replaced conventional plating. The nature of the fixed-angle screws precludes bone compression and angle variability, which are sometimes necessary depending on the situation and the anatomy. Articular fractures and simple fractures are still best treated with anatomic reduction and compression plating. Given fracture environments with impaired vascularity, such as nonunion or delayed unions, conventional compression plating techniques are necessary to maximize stability and healing potential.

Combination holes expand the versatility of these implants and serve as a useful adjunct to traditional techniques. Most importantly, the surgeon must decide in advance which principle to apply. Mixing screw types must be done with full insight into the ultimate composite plate construct, which has been planned to adhere to the principles of the strain theory. These new techniques and implants have changed the treatment concepts for many fractures, and early clinical results are promising. The surgeon may significantly improve fracture healing potential using one or a combination of plating methods, if a biomechanically sound construct is devised and planned preoperatively.

Authors' Disclosure Statement

Dr. Helfet wishes to note that he is a member of the Board of Directors of Synthes, Inc.

References

1. Arens S, Kraft C, Schlegel U, Printzen G, Perren SM, Hansis M. Susceptibility to local infection in biological internal fixation. Experimental study of open vs minimally invasive plate osteosynthesis in rabbits. *Arch Orthop Trauma Surg*. 1999;119:82-85.
2. Arens S, Eijer H, Schlegel U, Printzen G, Perren SM, Hansis M. Influence of the design for fixation implants on local infection: experimental study of dynamic compression plates versus point contact fixators in rabbits. *J Orthop Trauma*. 1999;13:470-476.
3. Rozbruch SR, Muller U, Gautier E, Ganz R. The evolution of femoral shaft plating technique. *Clin Orthop*. 1998;195-208.
4. Gardner MJ, Brophy RH, Mahajan A, Campbell D, Wright TM, Helfet DL, Lorich DG. The biomechanical behavior of locking compression plates compared with dynamic compression plates in osteoporotic bone. *J Orthop Trauma*. In press, 2004
5. Ganz R, Mast J, Weber B, Perren S. Clinical aspects of "bio-logical" plating. *Injury*. 1991;22(S1):S4-S5.
6. Leunig M, Hertel R, Siebenrock KA, Ballmer FT, Mast JW, Ganz R. The evolution of indirect reduction techniques for the treatment of fractures. *Clin Orthop*. 2000;7-14.
7. Kinast C, Bolhofner BR, Mast JW, Ganz R. Subtrochanteric fractures of the femur. Results of treatment with the 95 degrees condylar blade-plate. *Clin Orthop*. 1989;122-30, 1989.
8. Blatter G, Weber BG. Wave plate osteosynthesis as a salvage procedure. *Arch Orthop Trauma Surg*. 1990;109:330-333.
9. Haas N, Hauke C, Schutz M, Kaab M, Perren SM. Treatment of diaphyseal fractures of the forearm using the Point Contact Fixator (PC-Fix): results of 387 fractures of a prospective multicentric study (PC-Fix II). *Injury*. 2001;32(suppl 2):B51-62.
10. Muller M, Allgower M. *Manual of Internal Fixation: Techniques Recommended by the AO-ASIF Group*. Berlin: Springer-Verlag, 1991.
11. Tepic S, Remiger AR, Morikawa K, Predieri M, Perren SM. Strength recovery in fractured sheep tibia treated with a plate or an internal fixator: an experimental study with a two-year follow-up. *J Orthop Trauma*. 1997;11:14-23.
12. Miclau T, Martin RE. The evolution of modern plate osteosynthesis. *Injury*. 1997;28(suppl 1):A3-6.
13. Uhthoff HK, Dubuc FL. Bone structure changes in the dog under rigid internal fixation. *Clin Orthop*. 1971;81:165-170.
14. Akeson WH, Woo SL, Rutherford L, Coutts RD, Gonsalves M, Amiel D. The effects of rigidity of internal fixation plates on long bone remodeling. A biomechanical and quantitative histological study. *Acta Orthop Scand*. 1976;47:241-249.
15. Cordey J, Mikuschka-Galgoczy E, Blumlein H, Schneider U, Perren SM. [Importance of the friction between plate and bone in the anchoring of plates for osteosynthesis. Determination of the coefficient of metal-bone friction in animal in vivo]. *Helv Chir Acta*. 1979;46: 183-187.
16. Perren SM. Physical and biological aspects of fracture healing with special reference to internal fixation. *Clin Orthop*. 1979;175-196.
17. Nunamaker DM, Perren SM. A radiological and histological analysis of fracture healing using prebending of compression plates. *Clin Orthop*. 1979;167-174.
18. Klaue K, Kowalski M, Perren SM. Internal fixation with a self-compressing plate and lag screw: improvements of the plate hole and screw design. 2. In vivo investigations. *J Orthop Trauma*. 1991;5:289-296.
19. Cordey J, Borgeaud M, Perren SM. Force transfer between the plate and the bone: relative importance of the bending stiffness of the screws friction between plate and bone. *Injury*. 2000;31(Suppl 3):C21-28.
20. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. *J Bone Joint Surg Br*. 2002;84:1093-1110.
21. Miclau T, Remiger A, Tepic S, Lindsey R, McIff T. A mechanical comparison of the dynamic compression plate, limited contact-dynamic compression plate, and point contact fixator. *J Orthop Trauma*. 1995;9:17-22.
22. Johnston SA, Lancaster RL, Hubbard RP, Probst CW. A biomechanical comparison of 7-hole 3.5 mm broad and 5-hole 4.5 mm narrow dynamic compression plates. *Vet Surg*. 1991;20:235-239.

23. Borgeaud M, Cordey J, Leyvraz PE, Perren SM. Mechanical analysis of the bone to plate interface of the LC-DCP and of the PC-FIX on human femora. *Injury.* 2000;31(suppl 3):C29-36.
24. Olerud S, Danckwardt-Lilliestrom G. Fracture healing in compression osteosynthesis in the dog. *J Bone Joint Surg Br.* 1995;50:844-851.
25. Cheal EJ, Mansmann KA, DiGioia AM, 3rd, Hayes WC, Perren SM. Role of interfragmentary strain in fracture healing: ovine model of a healing osteotomy. *J Orthop Res.* 1991;9:131-142.
26. Gautier E, Sommer C. Guidelines for the clinical application of the LCP. *Injury.* 2003;34(suppl 2):B63-76.
27. Sommer C, Gautier E, Muller M, Helfet DL, Wagner M. First clinical results of the Locking Compression Plate (LCP). *Injury.* 2003;34(suppl 2):B43-54.
28. Field JR, Tornkvist H, Hearn TC, Sumner-Smith G, Woodside TD. The influence of screw omission on construction stiffness and bone surface strain in the application of bone plates to cadaveric bone. *Injury.* 199;30:591-598.
29. Ellis T, Bourgeault CA, Kyle RF. Screw position affects dynamic compression plate strain in an in vitro fracture model. *J Orthop Trauma.* 2001;15:333-337.
30. Cole PA, Zlowodzki M, Kregor PJ. Less Invasive Stabilization System (LISS) for fractures of the proximal tibia: indications, surgical technique and preliminary results of the UMC Clinical Trial. *Injury.* 2003;34(suppl 1):A16-29.
31. Goesling T, Frenk A, Appenzeller A, Garapati R, Marti A, Krettek C. LISS PLT: design, mechanical and biomechanical characteristics. *Injury.* 2003;34(suppl 1):A11-15.
32. Perren SM, Cordey J, Rahn BA, Gautier E, Schneider E. Early temporary porosis of bone induced by internal fixation implants. A reaction to necrosis, not to stress protection? *Clin Orthop.* 1988;139-151.
33. Perren SM. The concept of biological plating using the limited contact dynamic compression plate (LC-DCP). Scientific background, design and application. *Injury* 1991;22(suppl 1):1-41.
34. Eijer H, Hauke C, Arens S, Printzen G, Schlegel U, Perren SM. PC-Fix and local infection resistance—influence of implant design on postoperative infection development, clinical and experimental results. *Injury.* 2001;32(suppl 2):B38-43.
35. McKibbin B. The biology of fracture healing in long bones. *J Bone Joint Surg Br.* 1978;60-B:150-162.
36. Perren SM, Rahn BA. Biomechanics of fracture healing. *Can J Surg.* 1980;23:228-232.
37. Ruedi TP, Murphy WM. *AO Principles of Fracture Management.* Stuttgart-New York: Thieme, 2000.
38. Wagner M. General principles for the clinical use of the LCP. *Injury.* 2003;34(suppl 2):B31-42.
39. Krettek C, Haas N, Tscherne H. The role of supplemental lag-screw fixation for open fractures of the tibial shaft treated with external fixation. *J Bone Joint Surg Am.* 1991;73:893-897.
40. Perren SM. Backgrounds of the technology of internal fixators. *Injury.* 2003;34(suppl 2):B1-3.
41. Mast JW, Jakob R, Ganz R. *Planning and Reduction Technique in Fracture Surgery.* Berlin, Heidelberg, New York: Springer, 1989.

This paper will be judged for the Resident Writer's Award.