Locking Plates: A Current Concepts Review of Technique and Indications for Use

Úhlově stabilní dlahy: přehled současných názorů na techniku použití a indikace

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INTRODUCTION

Locking plates are important tools in the orthopedic surgeon's armamentarium. They have demonstrated tremendous effectiveness in dealing with challenging fractures yet the specific indications and techniques for their use is still the subject of considerable debate (2, 41). Inappropriate application of standard orthopedic operative principles may compromise patient outcome, frustrate surgeons, and considerably increase expense to orthopedic care (32, 37). This article reviews locking plates, general indications for use and fracture-specific indications organized by anatomical areas. It will highlight general locking plate principles, complications, and techniques for best utilization of this powerful technology.

HISTORICAL PERSPECTIVE

Locking plates have evolved from early efforts of indirect reduction, limited plate contact, and fixed angle constructs (16). Conventional plates combined with Schuhli nuts were the early precursors to today's locking plates (48). Eventually, threaded nuts welded to distal femoral plates demonstrated mechanical advantages in some fracture patterns (15). Many other incremental innovations led to the development of today's sophisticated pre-contoured, low-profile, locking plates. Surgeon demand for additional intraoperative options has led to the development of combination hole, variable angle, and fracture specific plates (12).

PREVALENCE

Today, locking screw technology is reportedly being used in 5–25% of all fractures (37). Early enthusiasm for locking plates has been tempered with poor evidence to support their use. The PC-fix and LISS plates represent early efforts that saw considerable uptake but were not supported by favorable clinical evidence to support their widespread use (1,35) With clinical review, important new clinical understanding of how these plates function and potential shortcomings have been highlighted (25).

COST

Locked implants typically are three to four times more expensive than comparable unlocked implants, and sometimes much more (38). The increased cost of the plate added to the increased screw costs may considerably increase the construct cost for a given fracture. Of course, the increased cost of the initial implant, may be offset by the cost and morbidity associated with an inappropriately fixed fracture or requirement for secondary operations (29).

GENERAL INDICATIONS

The general indications for locking plate use are not well defined (2, 14, 37, 42). AO has led the way in developing guidelines for use – however robust evidence-based indications have lagged behind clinical uptake. The following four general indications for use of locked plates in fractures:

Juxta-articular fractures (eg. short distal end segments, intramedullary canal too wide for intramedullary support, cortical bone too thin for substantive fixation, angular instability).

Fractures in osteoporotic or pathologic bone (eg. high risk patients with limited fixation options and at high risk of screw pull-out, toggle, and catastrophic collapse).

Revision procedures (eg. previous non-union, osteotomy, challenging fractures, previous hardware, periprosthetic fractures with limited fixation options around existing prostheses).

Biologic fixation (eg. bridging long segments of comminution. Locking holes and threaded guides may facilitate minimally invasive techniques. Limited plate contact to minimize insult to periosteal blood supply).

TECHNIQUE OF USE

Fig. 1. Long plates with relatively few screws are used to distribute load through the plate in order to maximize the working length of the plate.

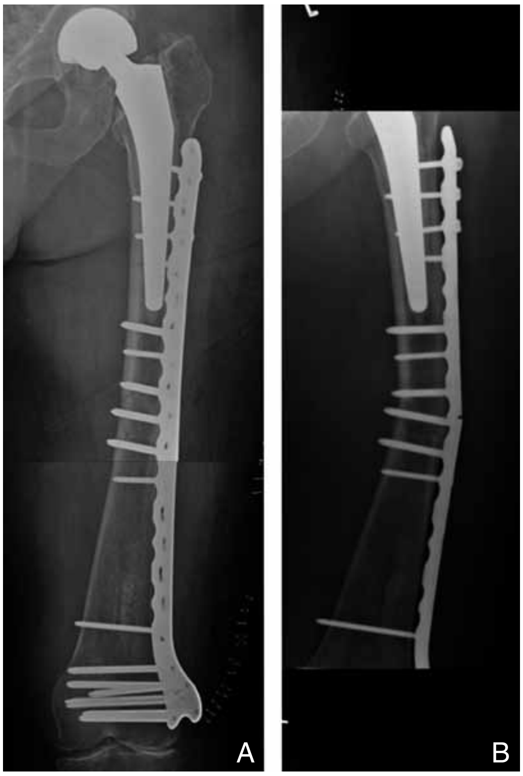

Fig. 2. Transverse fractures with a small fracture gap should be managed with longer working length plates to minimize the occurrence of fatigue fracture (A – construct is too rigid at the fracture site, B – eventual plate failure).

Locked plate constructs are based on a mechanical interface between a locking plate and locking screw. Many proprietary technologies exist, but in essence, screw rotation and trajectory is locked relative to the plate creating a fixed angle construct (31). The mechanism of this locking can be through conical threads on the screw and plate, locking caps over the screws, or interference fit.

Fundamentally, locking plate constructs differ from standard plate and screw constructs. Contact between the bone and plate is not necessary (26). By eliminating the need for friction between plate and bone, the risk of primary loss of reduction and disruption to bone blood supply is greatly reduced (42). Additionally, by eliminating movement between individual components there is a much greater resistance to screw pull-out, sometimes as much as four-times the conventional construct (13, 26).

Strain theory is very important to the understanding and application of locking plates. Perren, in 1979, advanced the original argument that fractures will heal by primary bone healing, secondary bone healing or proceed to non-union. Fracture strain is calculated by fracture gap displacement divided by fracture gap overall length (30). Low strain states (< 2%) – as present in absolute stability – will heal primarily – without callus formation. Medium strain states (2–10%) – seen in relative stability – will heal with secondary bone healing and abundant callus. Finally, high strain states (> 10%) typically proceed to non-union because the elasticity of fibrous tissue is required to accommodate the significant movement at the fracture gap (10).

Locking plate constructs are often long plates with relatively few screws used for relative stability, or short plates with multiple divergent screws used in juxta-articular fractures. The working length of a plate should be 2–3 times the length of the comminuted segment that it is spanning (Fig. 1), (26). To avoid premature failure of a locking plate – which most often occurs through the non-threaded portion of a combination hole – the working length across the fracture site should be maximized (Fig. 2). When the gap size is small (1 mm) increasing the working length of a plate will minimize the chances of plate failure. When the gap size is large (6 mm) significant demands are placed upon the screw bone interface and screw failure becomes more common (Fig. 3), (26). The distance from the fracture site to the adjacent screw is the most influential factor on the axial and torsional stiffness of the construct. A minimum of 3 screws should be installed in each main fragment (14, 26, 34).

Locking plates present surgeons with complex fixation options that have not been a part of many surgeons surgical training and sometimes have a contradictory purpose. Unicortical and far-cortical-locking screws are two fixation options with locking plates that continue to be hotly debated. With unicortical screws, the screw-plate threaded interface is often regarded as an additional 'cortex' providing axial stability and resistance to screw toggle eliminating the need for bicortical fixation (10). Initial enthusiasm around unicortical screw fixation was based on ease of installation and percutaneous techniques (16), however, unicortical fixation is now generally reserved for fixation around prostheses and in metaphyseal bone segments. Far-cortical-locking (FCL) is a concept that is being advanced to mitigate the hazards of excessively rigid locked constructs. FCL techniques attempt to maximize the advantages of an angle-stable construct by maintaining a rigid interface between screw head and plate, while minimizing the stiffness of the screw to facilitate movement at the fracture site and promote secondary healing and callus formation (5).

Fig. 3. To avoid an overly rigid construct fixation has been placed well outside the proximal and distal extent of the fracture. Intimate contact between the plate and bone is not necessary with locking constructs provided the reduction is acceptable.

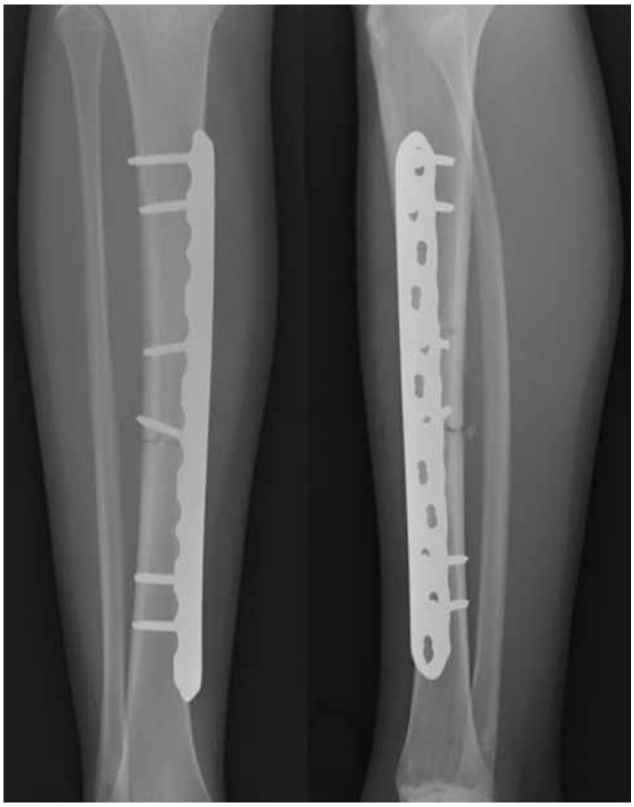

Fig. 4. A near-far construct was used to maximize rigidity and distribute load throughout the plate. This patient's tibia was plated due to significant respiratory issues.

This is an area of ongoing research to determine its clinical efficacy.

Finally, exact placement and pattern of screws in locking plate constructs is also debated. It is important to abide by standard orthopedic principles when installing screws and deciding whether relative or absolute stability is desired. With relative stability – in a large fracture gap model or fractures with extensive comminution – careful steps must be taken to minimize screw failure (34). On each side of the fracture, a single screw immediately adjacent to the fracture and a second screw distant (3–4 holes) from the fracture should be installed. A third screw should be installed, however, and it's effect does not vary much with the position between the other two screws. This pattern of screw installation is often described as a 'near-near, far-far' technique (Fig. 4), (26). Periprosthetic fractures remain a challenge and little data exists on the optimal type and placement of hardware but is often dictated by the prosthesis in place (36).

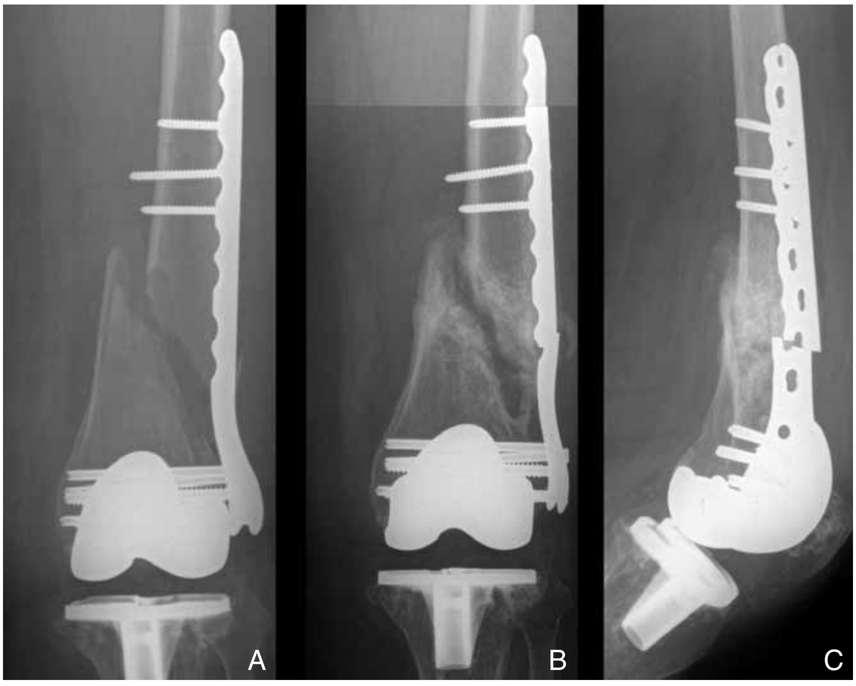

Fig. 5. A rigid locking plate combined with a sub-optimal reduction can lead to plate failure (A – immediate post-op, B and C – plate failure despite bone graft).

COMPLICATIONS

Incomplete understanding and inappropriate application of locking plate principles are probably the two most common reasons for failure of locking plate constructs. Locked constructs tend to be quite rigid, and in situations where relative stability is desired, inappropriate application can lead to increased non-union and delayed union (Fig. 5), (20, 39). Intra-articular cut-out is an inherent risk of fixed angle constructs in juxa-articular constructs (Fig. 6), (28). Insufficient working length of locking plates when bridging fractures may lead to premature plate fracture (Fig. 7), (12). Hardware removal can be complicated by plate-screw 'cold-welding' which can result in frustrating stripping of screw heads. Finally, limited or pre-defined trajectories in contoured plates can complicate indirect reduction attempts and push the surgeon to have a very thorough understanding of anatomy and individual plate mechanics in order to achieve an acceptable result (Fig. 8), (32).

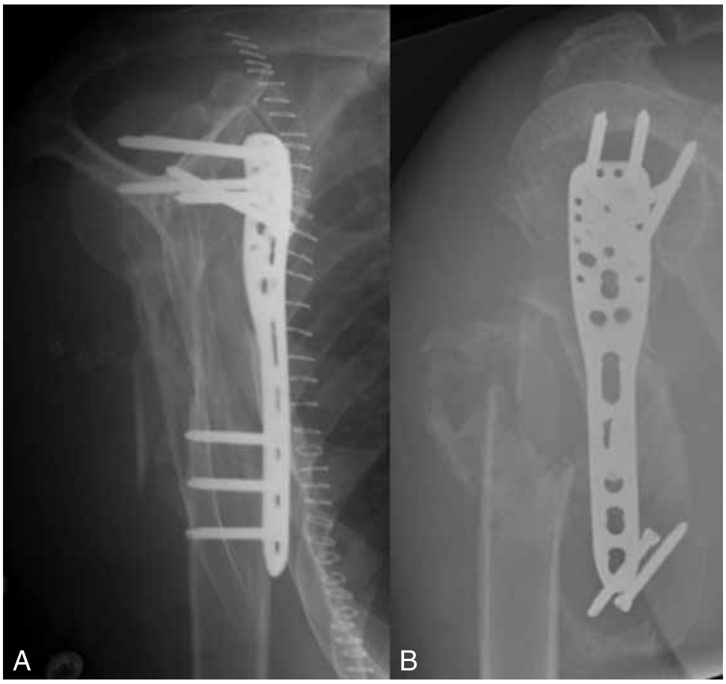

Fig. 6. Fixed angle constructs are susceptible to intra-articular cut-out as illustrated by this proximal humeral locking plate; (A – intra-op, B – 8 weeks post-op).

APPLICATION BY ANATOMY

Proximal humerus

A recent systematic review by Sproul et al., found that patients who fit the indications for open reduction and internal fixation of proximal humerus fractures, can expect higher functional outcomes when compared to hemiarthroplasty (33). Functional outcomes typically correlate with the complexity of the fracture. Technically, the first screw installed through a locking plate should be non-locking positioned just above calcar (37). Varus reduction is a strong predictor of failure (33, 37). Careful radiographic views must be obtained to ensure no articular penetration of hardware. The use of locked plates does not influence the rate of AVN observed.

Evidence: Prospective level one studies comparing locking plates to hemiarthroplasty are ongoing (22).

Humeral shaft

Operative humeral shaft fractures should be treated according to standard orthopedic principles. Locking plate fixation should be considered in osteoporotic or highly comminuted fractures with short end segments.

Evidence: Prospective level one studies comparing conventional plates to locking plates in humeral shaft are absent.

Distal humerus

Locking plates have been demonstrated to be advantageous for fixation of comminuted distal intra-articular humeral fractures over conventional fixation however this has not been thoroughly evaluated with Level 1 studies (9). Anatomic articular reduction through sufficient surgical exposure, combined with robust distal fixation using parallel plates, to allow early range of motion should be the goal of distal humerus fractures (46).

Evidence: Prospective level one randomized studies are absent.

Proximal ulna

There is no clinical evidence to strongly support the use of locking plates for olecranon and proximal ulna fractures. Precontoured plates with multiple proximal screws tend to be used in osteoporotic or highly comminuted fractures.

Evidence: Prospective level one randomized studies do not exist.

Midshaft forearm

Generally, forearm fractures should be managed with classic principles of absolute stability using conventional techniques (27). In challenging situations of short end-segments, extensive comminution or osteoporosis – locked plates may be considered. A minimum of 3 screws on each side of the fracture should be installed (14).

Evidence: Prospective level one randomized studies do not exist.

Distal radius

Distal radius fractures which meet operative indications are very commonly treated with volar precontoured locking plates. Despite their widespread use there is little evidence to support their use in elderly patients (3). Dorsal tendon rupture is a significant complication of prominent hardware (43). Volar locking plates may be used in the setting of unstable fractures, including dorsally comminuted fractures (33). Despite locking plates being associated with better

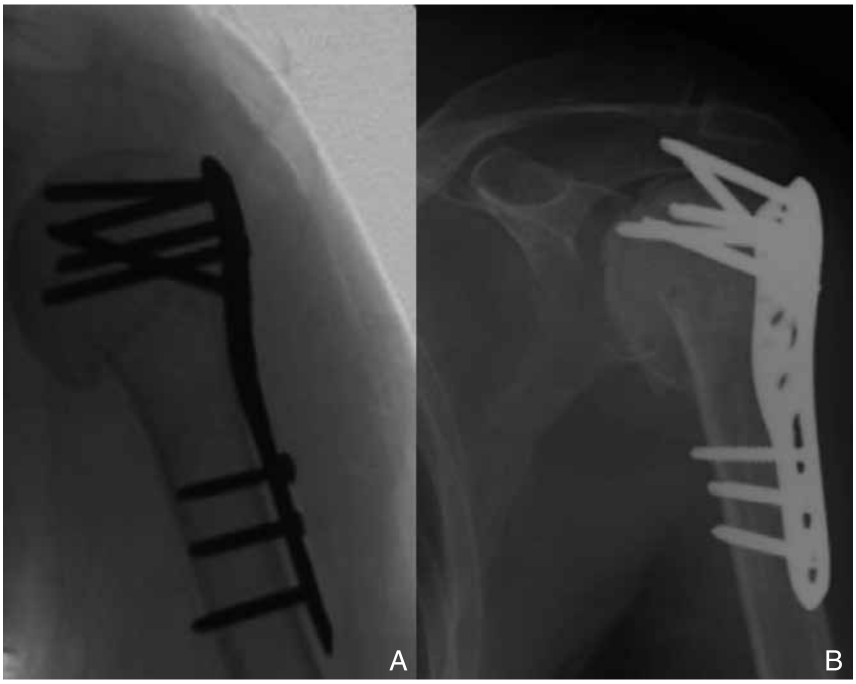

Fig. 7. Plate length should be a minimum of 2–3 times the length of the zone of comminution. (A – immediate post-op, B – construct failure).

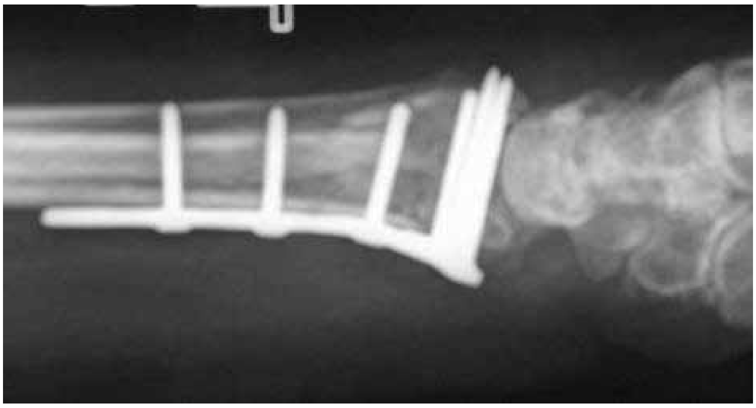

Fig. 8. Locking plates with fixed screw trajectories may lead to inadvertent intra-articular placement of hardware.

radiographic outcome, functional outcome is comparable to other surgical fixation options and patients should be carefully selected (23).

Evidence: Level 2 prospective data supports the use of locking plates, however, no Level 1 data comparing locking plates to non-locking plates exists.

Clavicle

Precontoured locking plates are popular for plating clavicles that meet operative indications, however, the use of locking screws has not been supported by good clinical evidence. Biomechanical research supports bicortical screws over unicortical screws for most applications (24). Achievement of absolute stability is desired to minimize malunion and non-union. Precontoured plates have been associated with lower rates of hardware complications (40)..

Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.

Pelvis

Pubic symphysis plating of unstable pelvic ring injuries has not shown advantages of locking hardware over conventional hardware (7). In exceptional circumstances such as osteoporosis or compromised fixation, locking hardware may be appropriate. *Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.*

Proximal femur

Complex fractures of the proximal femur treated with proximal femoral locking plates continue to demonstrate a high rate of major complications requiring reosteosynthesis or prosthetic implantation due to secondary loss of reduction (45). The dynamic hip screw and hip intramedullary nail are the main devices for clinical use, however they too are associated with high failure rates in complex fractures (19). Adequate reduction of the posteromedial buttress is an important factor for maintenance of reduction. Periprosthetic fractures with limited proximal fixation seem to be biomechanically well suited to locking plates, but this has not been supported with robust clinical data (36).

Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.

Femoral shaft

Intramedullary nailing remains the gold standard for diaphyseal fractures of the femur (37). Complex peri-prosthetic, juxta-articular, highly comminuted patterns, or fractures without a patent femoral canal are amenable to locked plate fixation.

Evidence: No Prospective Level one randomized studies comparing locking to non-locking plates exists.

Distal femur

Distal femoral locking plates are the implant of choice for distal intra-articular and peri-prosthetic fractures (17). The challenges of reduction, combined with the stiffness of the plates requires careful attention and selection of plate working length to minimize chances of nonunion. Comminuted fractures should have sufficient mobility to heal with callus formation and the tendency to place locking hardware through long spiral segments should be avoided. Where anatomic reduction can be obtained it should be used. Distracted fracture gaps heal poorly with rigid implants.

Evidence: There has been a single level one trial in this area but locking plates were not favored over older technology (LISS vs DCS), (6).

Proximal tibia

Tibial plateau fractures can benefit from locked plating in fractures with instability, metaphyseal comminution, and osteoporosis (11). The use of locking plates has not changed the basic principles of plateau management, and young patients with good bone quality can be adequately managed with conventional techniques (41). Locking plates installed through medial or lateral approaches may not adequately manage posterior comminution and careful understanding of the fracture mechanics is necessary to appropriately support these fractures (47).

Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.

Tibial shaft

Locked plates have a role in tibial shaft fractures if there is a concomitant intraarticular fracture, extensive comminution or where use of an intramedullary device is not possible. Treatment of non-unions with multiple previous fixation attempts may benefit from the use of locking plates (21).

Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.

Tibial plafond

Intra-articular fractures of the distal tibia may have improved outcomes with the use of locked plating. Complex fractures with extensive comminution requiring intra-articular reconstruction have fixation demands that are addressed with fixed angle constructs. Locking plate development contributed to renewed interest in minimally invasive techniques around the distal tibia. Minimally invasive techniques may demonstrate a decreased risk of disrupting the blood supply when compared to a classic open approach, however, significant clinical gains have not been consistently demonstrated (29). Little clinical evidence-based data exists to support the use of locking plates despite their widespread use.

Evidence: Prospective level one randomized studies comparing locking to non-locking plates do not exist.

Ankle

The vast majority of ankle fractures can be treated with conventional fixation techniques (44). In extreme osteoporosis and highly comminuted fractures, locking plates may be considered to augment distal fixation (18).

Evidence: Prospective level one randomized studies comparing locking plates to non-locking plates do not exist.

Foot

Challenging fixation in the small bones of the foot has led to the development of many locking options for surgeons. There is little clinical evidence to support locking plate application for specific fractures except for general locking plate indications (8). Despite widespread use, locking plate use in the calcaneus is not supported by robust clinical evidence (4).

Evidence: Prospective level one randomized studies comparing locking plates to non-locking plates do not exist.

FUTURE DIRECTION

Locking plate technology represents a significant advancement in fixation options for orthopedic surgeons. Despite the widespread clinical use and extensive commercial development, few absolute indications exist for their use. Furthermore, there is a notable paucity of level one clinical studies that compare conventional and locked plating options. Anyone using locked plating techniques must have a thorough understanding of how the biomechanics of locked plating differ from conventional plating, specifically related to plate length and screw position. The rigidity of locked constructs can often delay or inhibit healing if improperly applied. Despite the hazards and complications associated with locked plating, these plates represent a very important tool for managing complex fractures and represent exciting research opportunities for clinical scientists.

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