

The role of locking technology in the upper extremity

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Abstract The technique of locked plating has been a major advance in Orthopaedic fracture surgery and has had an equal impact on the management of upper extremity fractures. The recognition of the role of vascularity and soft tissues in fracture healing was central to the research and development of newer plate designs that left minimal footprints on the surface of the bone. Subsequently, innovative locking technology has improved our ability to manage cases with extensive comminution, inadequate bone stock, and peri-articular fractures. This paper will review the role of locking technology in the management of fractures of the upper extremity.

Keywords Locking technology · locking screws · locking plates · distal radius · proximal humerus

Introduction

The technique of locked plating has been the next major advance in Orthopaedics since the introduction of intramedullary nails and the introduction of Dynamic Compression Plates (DCP) by Professor S.M. Perren to the world of fracture care. Its evolution and development was driven by the tectonic shift that took place in the philosophy of fracture care principles over the last few decades [1].

Historical background

Over the last 60 years the principles of fracture fixation as laid out by the AO group have undergone fundamental changes in order to promote biological osteosynthesis.[2] The recognition of the role of vascularity and soft tissue conservation in fracture healing was central to the research and development of newer plate designs that left minimal footprints on the surface of the bone. This led to the search for ‘Internal Fixators’; devices that would provide locked fixation while maintaining little or no contact with the bone. (see Fig. 1) The internal fixators required new screw designs which could lock into these devices and negating the need for friction between the conventional plate and the bone surface [3, 4]. The Schuller-Nut, the Point Contact Fixator (PC-Fix) and the Less Invasive Stabilization System (LISS) plate were born out of such endeavors. Current plate designs offer flexible options to the surgeon in terms of locked vs. non-locked plating, fixed angle vs variable angle locking and open vs. percutaneous placement [5].

Biomechanics

When standard non locking plates are used, tightening of the screw leads to compression of the plate against the bony surface. The friction between the plate and the bone provides stability to the construct. The screw heads are free to toggle in the plate holes and hence bicortical purchase is needed to prevent loss of stability [6, 7]. The dis-

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advantage of this system is that the periosteal blood supply along the undersurface of the plate is lost. Locked plates act as fixed angle devices by allowing the screw heads to lock into the plate holes. Thus they can function as internally applied external fixators which do not have to rely on the friction at the plate bone interface for stability. This becomes an important issue when dealing with comminuted fractures which are commonly treated with bridge plating. Bridge plates span long segments of comminution and hence have a long working length. The working length of a plate bone construct is the length of the plate which is unsupported by screws. A long working length reduces the stability of the construct [8]. Such plates are frequently needed in periarticular locations with short end segments to bridge metaphyseal comminution. The short end segments with cancellous bone adjacent to joints further reduce the stability of the plate bone construct [5, 9, 10]. It is especially in these situations that locked plating offers the most advantages. While non-locked plates can function efficiently in the case of simple diaphyseal fracture patterns with good cortical contact for load sharing, they can fail in the case of osteopenic bone or bone loss and/or comminution at the fracture site. Locked plating overcomes these weaknesses by providing angularly stable fixation of the plate bone construct. They can be inserted percutaneously with or without jigs further adding to their usefulness by preserving vascularity. Since these devices function as internally applied fixators in the locking mode their ability to sit closer to the mechanical axis of the bone increases the stability over that provided by external fixators [11].

Innovations

The Schuli-Nut (Synthes, Paoli, PA) was one of the earliest attempts at providing angular stability to the screws



Fig. 1 A locked Limited Contact Dynamic Compression Plate (LC-DCP) showing the placement of a locked screw in the plate versus a non locked screw.

placed in non locking plates. It was a threaded washer which locked the screw head into the hole and also kept the plate off the bone surface [12]. Koval et al modified a condylar buttress plate to provide locked fixation for distal femur fractures in elderly patients. Cadaveric study demonstrated that this construct was more stable as compared to conventional plates [13]. The PC-Fix (Synthes) was one of the earliest implants designed to be an internal fixator using morse taper locking between the screw head and the plate holes [14]. The LISS (Synthes) was the first commercially available locked plate for periarticular fixation [6]. Both the LISS plate and PC-Fix provided only locking screws options and were designed for unicortical screw fixation in the diaphysis. The confluence of design principles of the compression plates and the early locking plates led to the development of the combination hole which allows for both locked and non-locked fixation [15]. These holes have been universally adopted in newer generations of periarticular implants and the LCPs. The threaded hole used for locking allows for only a fixed trajectory of the locking screw and this may be a problem in periarticular locations or preexisting lag screws because of screw traffic. The variable angle locking screws have been designed to overcome this disadvantage. These screws depend on hoop stress or some additional interface with the screw hole for locking. No studies are currently available comparing the variable angle locking screw designs to the threaded locking hole [16].

Indications and techniques

Locking plates have been in use mainly for periarticular fractures which are associated with problems of comminution, short bone segments, inability to gain bicortical purchase, and inadequate bone stock. Straight LCP plates are also available and these can be used when bridge plating diaphyseal comminuted and segmental fractures or in treating geriatric fractures with osteopenia. The additional cost of using locking screws cannot be justified in case of simple fracture patterns involving areas that have been treated successfully with conventional systems. These include diaphyseal fractures of the humerus and forearm [17]. In contrast, a more appropriate indication for locked plating in the upper extremity is proximal humerus and distal radius fractures [16].

Indications [16, 18]

1. Intraarticular fractures
2. Periarticular fractures (i.e. Proximal Humerus, Distal Humerus, Olecranon, Distal Radius)
3. Extraarticular metaphyseal fractures with comminution
4. Comminuted/segmental fractures
5. Periprosthetic fractures

6. Geriatric fractures/osteoporosis

Certain technical details are helpful when using these locked plating systems[18]

1. Ensure that the correct inventory is available well in advance of the surgery.
2. Ensure familiarity with the system that is going to be used. Refer to product manuals if needed.
3. Plan approaches and intraoperative steps of reduction before surgery.
4. Reduction and or compression must be achieved before locking screws are applied on both sides of the fracture. Once locking screws are positioned in a fracture fragment no further manipulation of that particular fragment is possible.
5. Temporary reduction may be maintained by multiple K-wires passed independently or through the plate.
6. When compression or reduction using the plate is needed, locking screws may be added after placement of compression or nonlocking screws for improving the strength of the construct.
7. Indirect reduction techniques with the help of distractors and percutaneously applied clamps are useful in minimally invasive plate application.
8. The fixed angle locking screws must be used with the jigs or drill guides provided by the manufacturer, otherwise crossthreading can occur with resultant reduction of stability.
9. Torque limiting screwdriver attachments must be used to prevent cold welding of screws into plate holes.
10. Intraoperative fluoroscopy to obtain orthogonal views is helpful to prevent joint penetration when placing periarticular screws.

Locked plating in the upper extremity

Proximal humerus

Proximal humerus fractures are relatively common and account for 5–9% of all fractures. Approximately more than 70% of proximal humerus fractures occur in individuals 60 years old or over with women being affected 3 times more than men [19]. The incidence of proximal humerus fractures is increasing in the elderly and is expected to triple over the next three decades [20]. The treatment of nondisplaced fractures has historically been nonoperative management with good outcomes whereas displaced fractures have generally been treated surgically [21, 22]. A plethora of surgical techniques has been described which includes percutaneous fixation, conventional plating, intramedullary fixation with rods or pins, tension band fixation with or without plates or rods, modi-

fied blade plate constructs, and hemiarthroplasty [23]. There is no consensus regarding the optimal treatment for these fractures. The vast array of available surgical options only proves the challenge faced by surgeons in treating these fractures and the rate of complications is high [16]. The osteopenic bone in the elderly patients combined with the short proximal segments and comminution provides very poor stability for fixation constructs. The poor results associated with internal fixation have prompted authors to recommend hemiarthroplasty for displaced 3 and 4 part fractures in the past [24–27]. Early results with the use of newer angle stable locking implants in these fractures have been encouraging and the use of such implants has extended the ability to preserve and retain the humeral head in greater number of patients [28] (see Fig. 2).

Locked plates designed specifically for the proximal humerus are anatomically contoured to fit the proximal humerus and provide multiple fixed-angle points of fixation into the humeral head. Each screw acts as a miniature blade plate, with the added benefit of providing fixed-angle support in multiple planes [16]. Open reduction and internal fixation (ORIF) with a locked plate is indicated for displaced two-part surgical neck fractures, two-part anatomic neck fractures in the patient younger than age 40 years, three-part surgical neck fractures with involvement of the greater or lesser tuberosity, and most four-part fractures. In the case of a fracture dislocation, ORIF is advisable in patients younger than 40 years. However the three and four part fractures or fracture dislocations in the elderly may be better treated with hemiarthroplasty [28]. Biomechanical data support the use of

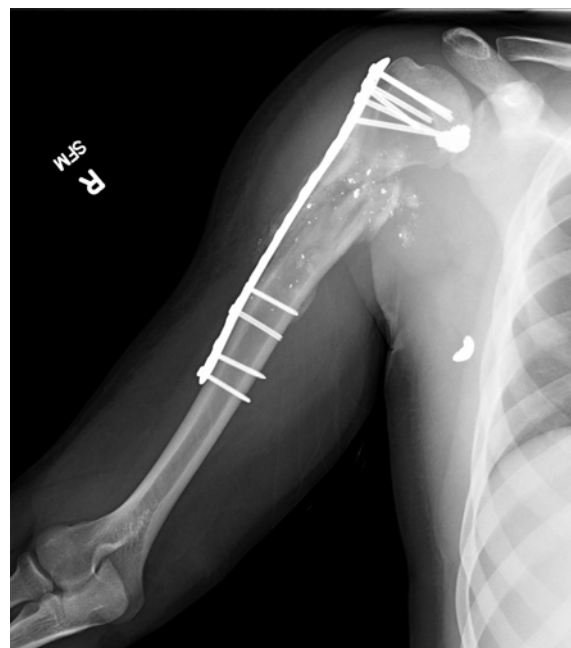


Fig. 2 Locked plate on a proximal humerus.

locked plating for proximal humerus fractures and recommend it especially for use in osteoporotic bone [29–31].

Despite the improved fixation offered by the locked implants, the failure of such constructs has been reported. The usual modes of failure are secondary to collapse of the osteoporotic head around the plate, screw cutout, failure of the locking interface or failure of the plate along the working length of the plate [32, 33]. Inferomedial screw placement has been recently shown to reduce the risk of varus collapse in these fractures [34]. The early results with the use of locked implants have been promising in the treatment of these fractures. The incidence of fixation failure is between 3–12%, that of infection being around 8% and other complications like impingement and nonunion reported infrequently [35–38]. The low rates of complications associated with satisfactory clinical outcomes (constant scores between 72 and 77) makes these implants very promising [35, 38, 39]. The risk of osteonecrosis is considered to be one of the indications for recommending shoulder hemiarthroplasty in 3 and 4 part fractures and fracture dislocations. The incidence of osteonecrosis in these types of fractures treated with locked plating is up to 16% [40, 41]. Recent data is also available to help determine which fractures are at an increased risk for developing osteonecrosis or other complications [42]. However the functional results obtained with locked plating are better than those obtained with arthroplasty for three and four part fractures of the humerus. Constant scores following hemiarthroplasty for these fractures are between 46 and 68 compared to average Constant scores of between 57 and 78 for locked plating [35, 38, 41, 43–45]. Except for one study, no other direct comparisons with other implants have yet been reported [46]. Despite this, surgeons have widely adopted the locked implants in view of the potential benefits [16, 28].

Distal humerus

Fractures of the elbow constitute about 7% of adult fractures with distal humerus fractures constituting less than half of all elbow fractures [47]. However recent epidemiologic data showed the number of osteoporotic fractures of the distal humerus in elderly women is increasing more rapidly than can be accounted for by the demographic changes alone. It is significant to note that if the current trends continue; a three fold rise in the number of distal humerus fractures is projected by the year 2030 [48]. In elderly patients with significant osteopenia and comminution of the joint, semiconstrained total elbow arthroplasty is the recommended treatment if the elbow joint cannot be reconstructed [49]. For displaced, unstable distal humerus fractures amenable to stable fixation, open reduction internal fixation is indicated to provide the best outcomes [47, 50, 51]. It has been shown that functional

results after treatment of these fractures correlate negatively with the degree of intraarticular involvement and the period of immobilization. The treatment of these fractures is also associated with a high rate of complications which include loss of fixation and implant failure. Stable implant anchorage provides the necessary fixation to start early range of motion and prevent complications in these challenging fractures with good to excellent outcomes in most patients in both the short term as well as the long term period [52–58]. While in good bone quality implant choice is not critical, biomechanical laboratory results have shown that locking plate constructs help maintain anatomical reduction in the presence of comminution and poor bone quality in a low intra-articular fracture of the distal humerus [59]. Various anatomically preshaped angular stable implants are now available which facilitate operative reduction and stabilization of the fractures of the distal humerus. Studies have also suggested that plate configuration may also assume importance in providing stable osteosynthesis [60]. Double-plating has been shown to provide more rigid fixation than a single-locked plate for fixation of extra-articular comminuted distal humeral fractures [61]. Studies have demonstrated that stiffness in anterior/posterior bending and torsional loading is significantly increased by using locking compression plates in a 90 degrees configuration as compared with dorsally applied plates. However this difference between the different plate types is insignificant if applied in the same configuration [60]. While traditionally the construct promoted by the AO group involves plate application on the two pillars of the distal humerus in a perpendicular configuration (90–90 construct) [62–64], recent studies by O'Driscoll et al. have claimed that this concept is unsubstantiated and incorrect. Several studies claim that a construct with two locking plates placed in a parallel configuration on either column in the sagittal plane with interdigitating screws linking the two columns distally in the form of an arch is a stronger construct as compared to the 90–90 construct [65–68]. Since only retrospective clinical data from only specialised centers is available currently without any prospective randomized trials comparing the two methods, firm conclusions cannot be drawn regarding the superiority of one method over another.

Proximal radius and ulna

Olecranon fractures are intraarticular injuries requiring accurate restoration of the joint surface. These injuries range from simple nondisplaced fractures to comminuted fracture dislocations. Numerous fixation methods have been described and include screw fixation, cerclage wiring, modified tension-band wiring, and plate fixation. The surgical technique depends on a combination of patient factors, the fracture pattern, and the mechanical stability

of the fixation construct. Fixation must be stable enough to permit early mobilization to avoid significant elbow stiffness [69–71]. Plate fixation is commonly recommended with comminuted fractures and fractures distal to the midpoint of the trochlear notch, those involving the coronoid process and olecranon fractures associated with Monteggia fracture dislocations of the elbow. Tension Band wiring or conventional plating may not provide adequate stability in these situations [72, 73]. A plate applied over the dorsal tension surface of the olecranon with an intramedullary screw through the proximal hole has been shown to be most stable construct in biomechanical studies and may, therefore, be the preferred method of fixation for comminuted olecranon fractures [74]. Several precontoured and congruent plate constructs are available for olecranon plating with the option of locking screws for added stability. Plate fixation has been shown effective treatment option for displaced olecranon fractures with a good functional outcome and a low incidence of complications [75, 76].

While ideal treatment of radial head fractures is associated with controversy, radial head open reduction and internal fixation is currently the preferred method of treatment, whenever feasible, to restore elbow alignment and stability [77–79]. Several studies have shown favorable results with the use of plate fixation for radial head fractures [78, 80–83]. Biomechanical studies have shown comparable or even higher stability in unstable radial head fractures with angle stable implants as compared to crossed screws or nonlocking plates [84, 85]. The role of locking plate technology in these fractures needs to be clarified with biomechanical testing and randomized prospective studies with a focus on validated outcome instruments.

Distal radius

The lifetime risk of developing a distal radius fracture is 15% for women and 2% for men [86]. These fractures represent the second most common fractures in the elderly after hip fractures and account for one-sixth of all the fractures treated in the emergency department [87]. The attitude towards the treatment of this common injury is changing as it is becoming clear that the restoration of anatomical articular congruity is critical [88]. There is a correlation between the functional outcome following a distal radial fracture and the restoration of both the radio-carpal and the radioulnar relationships [89, 90]. In cases of fractures of the distal radius in elderly patients with osteopenic bone obtaining stable fixation and maintaining reduction till fracture healing represents a challenge. Theoretically locked plating represents a perfect solution for the problems associated with these fractures since many of them are associated with short end segments, metaphyseal and/or articular comminution and osteopenia.

(see Fig. 3) Indications include any distal radius fractures whose potential for collapse or loss of articular reduction exceeds the level of stabilization that can be provided with closed reduction and smooth wire stabilization. The more osteopenic or metaphyseally deficient the bone, the more advantageous volar fixed-angle plating is [91]. There has been a marked trend in favor of plate and screw fixation for fractures of the distal radius. The proportion of fractures that are stabilized with open surgical treatment have increased from 42% in 1999 to 81% in 2007 [92]. Biomechanical studies have shown better stability in osteopenic distal radius fractures with locked plate fixation [93–96]. However there is little Level-I or II evidence to support open reduction and locked plating for distal radius fractures [97–100]. The Cochrane Musculoskeletal Registry after a recent review of randomized controlled studies, concluded that the literature does not provide robust evidence for most of the decisions regarding surgical intervention in the case of distal radius fractures [101]. Despite lack of evidence the popularity and use of locked plating for distal radius fractures continues to surge. Implant manufacturers offer more than thirty different designs of locked plate implants with multiple screw options (locking vs non-locking, variable angle vs fixed angle locking, smooth pegs vs screws) and the market



Fig. 3 Locked volar locked plate on a distal radius.

for distal radius implants alone grosses \$250 million [102].

Mechanical failures are rare in cases of distal radius fixation constructs because of the reduced loads about the wrist. However, minor amounts of settling of the distal fragment have been reported. Placement of the distal screws or pegs just beneath the subchondral bone is supposed to improve the stability and prevent settling or re-displacement [103, 104]. Volar locked plating for osteopenic or high energy comminuted distal radius fractures has provided satisfactory outcomes and times to union even with institution of early range of motion as compared to other modalities [91]. Times to union have generally been between 7–8 weeks with an average range of motion which was better than fractures treated with external fixation [105, 106]. Satisfactory results with locked plating of distal radius fractures have also been obtained with the use of validated outcome instruments like the DASH score for assessment. An average DASH score from 8.3 to 16 (range 0–100, with a lower score better than a higher score) and an average grip strength of around 75–77% may be expected [103, 106]. Complications related to tendon and soft tissue irritation are uncommon with volar plating as the flexor tendons are not in contact with the plate. Also the pronator quadratus acts as a soft tissue cushion between the tendons and the plate. Complications have been reported due to overpenetration of screws through the dorsal cortex, intraarticular penetration and radial artery injury. Variable angle locking screws may help in prevention of joint penetration and interference with other hardware [107]. Fracture settling due to inadequate support of the subchondral bone by the distal screws can also occur [91, 108–112].

Studies have proven that external fixation augmented with percutaneous pins provides superior radiographic results as compared to closed treatment or pin fixation alone [113, 114]. Comparable results have also been obtained with external fixation augmented with pin fixation versus open treatment in terms of radiographic outcomes and clinical results [106, 115]. While external fixation with or without percutaneous pins is a definite improvement over closed techniques of treatment, it is associated with complications. Tightness of the digital extensors, wrist capsular stiffness, osteopenia, radial sensory nerve problems, malunion, nonunion, pin-tract infections, and regional pain syndrome are common problems and final range of motion, pain, grip strength, and outcome scores can be adversely affected in direct proportion to distraction and duration of external fixation [116, 117]. The dorsal plating approach to distal radius fractures evolved as a means to buttress the common tendency of these fractures to displace dorsally. However dorsal plating is associated with complications related to extensor tendon irritation and rupture [118–120]. The enthusiasm for volar locked plating is also driven by the various reports documenting

excellent results with the volar locked plate fixation of the common dorsally displaced fractures [105, 121–123]. However it still remains unclear if the use of locked plating translates into clinical benefits when compared with non-locked plating, dorsal plating or external fixation modalities in the long term. While the surge in popularity of locked plating continues, the need for randomized controlled trials with the use of validated outcome measures to prove the superiority of this technique over other modalities remains.

Advantages, disadvantages and complications

Surgeons develop a sense of tactile feedback with regular nonlocking screws to determine screw purchase. This is essential in order to determine the overall stability of the construct. No such feedback is available for the surgeon in case of locking screws. Traditional screws allow the plate to be sucked down to the bone or vice versa. This quality is frequently used to aid reduction of fractures to the plate. Since locked plating does not offer this advantage it can only be used to maintain reduction and not to gain it. When locked plates are used for percutaneous application, the inability to gain reduction may lead to a higher rate of malalignment as compared to open reduction. Attempts to contour the locking plates can lead to loss of screw head fixation within the holes, leading to decrease in stability of the construct. This is a problem when using precontoured locking plates for periarticular fractures as the bony anatomy varies between individuals in terms of shape and size. Hardware removal can become difficult if the screw heads get cold welded into the locking holes especially in the case of titanium plates. Torque limiting attachments are available for the screw drivers and power tools so that the incidence of this complication can be decreased. The use of fixed trajectory locking plates in periarticular locations has a potential disadvantage of screw penetration into the joint or interference of the screw with other screws especially in complex fractures. Use of nonlocking screws through locking holes is not advisable as the round locking holes do not allow a great freedom in terms of screw direction and the screw heads can be too prominent. Variable angle locking plates are available but the stability provided by such designs has not been well established. Early locking plate designs meant for percutaneous insertion used unicortical screws in the diaphysis and this was associated with fixation failure. The locking screws also do not allow any compression at the fracture site as the screw heads cannot move within the hole. These disadvantages have been overcome with the development of newer plate design which allow for both bicortical fixation and the option of using non-locking screws if needed. Locked plate constructs are also much more expensive than their conven-

tional counterparts. A significant part of this cost increase can be accounted for by the cost of locking screws. The remaining cost increase arises from the need to maintain additional inventory and implants apart from training of OR personnel and staff. While these plates are commonly used in the developed countries, the use of these techniques and availability of opportunity for training and skill development in locked plating is not universally available in the rest of the world. Universal availability of industry support and implants may also be a problem in developing countries.

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