CiSE
Clinics in Shoulder and Elbow

Orthogonal versus Parallel Plating for Distal Humeral Fractures

Jun-Gyu Moon✉, Ji-Ho Lee

Department of Orthopedic Surgery, Korea University Guro Hospital, Seoul, Korea

In orthopedic trauma surgery, treatment of intraarticular distal humerus fractures is a challenge. With development of implants and biomechanical studies, surgical strategies with recommendations including preoperative computed tomography images, proper approaches and open reduction and internal fixation with dual plates have emerged. In addition, as an effort to provide stable fixation to permit early elbow motion, different methods of internal fixation, particularly plate configuration, have evolved. Using dual plates, either oriented parallel to each other or orthogonal, stable fixation has been achieved and satisfactory clinical outcomes have been reported. With rationales and advantages/disadvantages of each plate configuration, both techniques are selected according to surgeons' preference, and, in specific cases, one could be preferred over another. The key to successful fixation by either technique is obtaining anatomical reduction with restoration of two stable columns of the distal humerus.
(Clin Shoulder Elbow 2015;18(2):105-112)

Key Words: Humerus; Humeral fractures; Fracture fixation

Introduction

Fixation of distal humerus intraarticular fractures represents a challenge to surgeons attempting to address this problem as it is complicated by the anatomy of the elbow, its small area for fixation and otherwise compounded by comminution and osteopenia of articulating surfaces. Historically, fractures seen in the distal humerus have been recognized as complex articular injuries that are difficult to address and have poor outcomes with permanent disability to the involved extremity.[1-3] New implant designs and surgical techniques have improved through the years to help surgeons in management of these fractures. The main goal is to achieve a stable, accurate articular and bony reconstruction that allows early range of motion for rehabilitation and eventually a successful functional outcome.[3] In management of such fractures surgeons are required to observe several factors when considering plate fixation. These factors include, fractures patterns, quality of the bone, location of the implant, and the biomechanical properties of the implants.

Complex fractures of the distal humerus are not amenable to single column plating systems, which are proven to be less stable to loads compared to double column plating methods.[2,4] Based on clinical and biomechanical studies, fixation with double plating is currently recommended.[2,5,6] Dual plating is either an orthogonal configuration (perpendicular, 90-90 plating), with placement of one plate on the medial column and the other plate along the posterolateral column, or parallel configuration, with placement of one plate on the medial column and the other plate along the lateral column.[3]

Anatomy of the Distal Humerus

The distal humerus is composed of the lateral and medial columns which diverge distally with the trochlea in between to form a triangular construct. Disruption of the architecture of this triangular construct leads to loss of stability. The distal humerus also has 3–5° of internal rotation relative to the trans-epicondylar axis, 4–8° of valgus and 30° of anterior angulation with respect to the long axis of the humerus.[2] The lateral column diverges around 20° from the axis of the humerus and extends to the lev-

el of the distal portion of the trochlear articulating surface in the coronal plane. The upper half of the lateral column is composed of cortical bone while the distal half is composed of cancellous bone. Medial column diverges approximately 45° from the humeral axis then extending distally and terminates approximately 1 cm proximal to the distal level of the trochlea. The medial column is composed of cortical bone on its proximal two thirds while the remaining distal third is made up of cancellous bone to form the medial epicondyle. The terminal humerus is very thin between the lateral and medial columns at this particular level as the medullary canal becomes tapered 2 to 3 cm proximal to the olecranon fossa.[1,3)

In surgical approaches, management of ulnar and radial nerve is important to avoiding iatrogenic injury to preserve function and should be protected when proximal exposure of the humerus is required. The ulnar nerve is freed from the triceps muscle as far as necessary to obtain exposure proximally. In an effort to identify and protect the radial nerve, it can be identified on the lateral side, when a more proximal exposure is necessary, as it enters the lateral intermuscular septum, and identifying the point of confluence between the lateral and long heads of the triceps with the triceps aponeurosis provides an easily identifiable superficial landmark along the posterior approach to the humerus. To prevent injury of the radial nerve crossing in this area, utmost care should be strictly observed not to dissect proximal to the distal one-fourth of the humerus.[7-11)

Orthogonal Plating

The orthogonal plating technique is a system where the plates are positioned at 90° angles to each other situated on the medial and posterolateral column. Several different companies came up with implants of their own designs, but with similar characteristics. This plating technique was developed to address the failure of dual posterior plating which did not provide sufficient stability and resulted in nonunion and stiffness caused by prolonged immobilization.[12,13)] The AO group has proposed the orthogonal plating system to achieve maximum stability allowing early range of motion exercises.[2,12,14)] Their recommended technique included fixation of the articular fragments with screws and column stabilization with two plates at a 90° angle to one another. The previously used 3.5 mm reconstruction plate showed insufficient fixation strength in osteoporotic patients. The recently introduced locking precontoured plates have been widely used.

The posterolateral plate can be positioned as far distal as the posterior edge of the capitellar articular surface. Posterior to anterior screw fixation provides better purchasing power in the coronal fractured fragment of capitellum. On the other hand, application of the medial column plate requires placement along the sagittal plane on the supracondylar ridge that will curve around the medial epicondyle (Fig. 1).

Parallel Plating

This plating technique involves plating of the lateral and medial column in a parallel manner or 180° position in contrast to orthogonal plating. The concept of this plating technique originated from the poor outcomes in some patients who underwent orthogonal plating. Orthogonal plating was not adequate for all cases and this orthogonal plating system was inadequate for osteoporotic, comminuted fractures, which result in nonunion, metal failures, and stiffness.[15-17)] In contrast with orthogonal plating, the lateral plate is situated along the supracondylar ridge in the sagittal plane and is contoured in a 'J' manner distally to fit
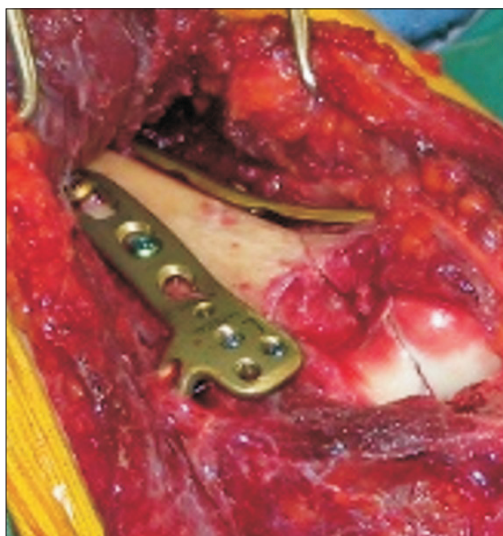

Fig. 1. Intraoperative view of fixation using orthogonal plating. Note that the posterolateral column is fixed with a precontoured locking plate.
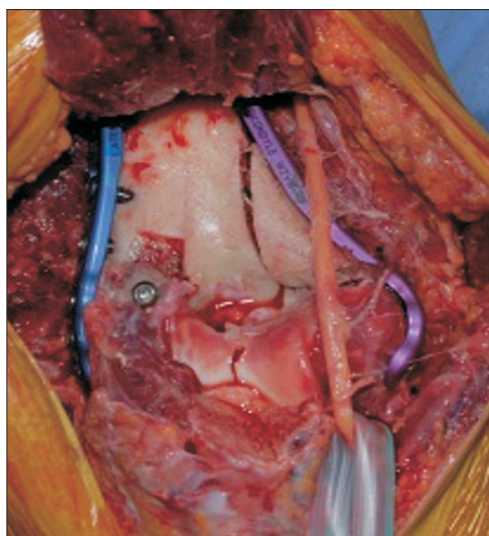

Fig. 2. Intraoperative view of fixation using parallel plating. Note that both plates are parallel and fixed along the medial and lateral column.

the anterior angulation of the lateral epicondyle (Fig. 2). The positions of the plates are actually a little offset posteriorly and are not directly medial or lateral. Once initial fixation of the fracture is complete, the plate is then applied and the medial and lateral proximal cortical screws are purchased to hold the plate.[2,18,19] The concept of parallel plating follows the principles of architecture where two columns are anchored at their bases and joined together at the top.[20] Fixation of the bony fragments relies on the stability of the hardware structure and not on the screw purchase in the bone and adds stability to the 'arch'. Long screws inserted in the distal fragments interdigitate and are locked together and converted into fixed-angle screws. Ideally, the screws should pass through a plate from one side and into a bone fragment on the opposite side that is also fixed to another plate. This principle of creating a fixed angle screw strengthens fixation in the distal fragments. In their study, Sanchez-Sotelo et al.[18] noted that the Mayo clinic group suggested the idea of parallel plating using the principles of strengthening fixation of the distal fragments while achieving stability at the supracondylar level.

Biomechanical Comparison

Contradictory outcomes of the biomechanical testing of these two plating systems regarding which is superior over the other have been reported in the literature. In their biomechanical study of ten epoxy composite left humeri, Schwartz et al.[21] noted that both systems demonstrated similar mechanical stiffness, theoretically providing similar fracture stabilization. Plate strain differences may affect fragment position, but it is unclear how much loading occurs in vivo. They found that in the 90° construct, the longitudinal strain was significantly lower in axial compression, whereas the 180° parallel plating showed significantly lower transverse strain during axial torsion. In their study of AO/OTA C-3 fractures in 10 cadaveric elbows, Got et al.[22] noted that the 90-90 plate fixation had significantly greater torque to failure load compared to parallel plating. However, both techniques had the same mode of failure in torsion, and no significant difference in the stiffness of fixation of the articular segment or the entire distal segment during anteroposterior loading was observed between the two techniques. Self et al.,[23] who demonstrated the biomechanical properties of the two systems using reconstruction plates, noted that the parallel system was stronger and stiffer. In their study of 24 humeri with simulated AO type C2 of female cadavers aged between 68 to 87 years of age using locked plates, Stoffel et al.[24] demonstrated that stability was dependent on bone quality and noted that the parallel plating system was superior and showed significantly higher stability in compression and external rotation with greater ability to resist axial plastic deformation. Penzkofer et al.,[25] in an artificial bone model with simulated AO/OTA type C2-3, noted that the parallel plate demonstrated the highest bending stiffness and median

fatigue limit in extension, whereas in flexion, the 90-90 plating demonstrated the highest bending stiffness. In their biomechanical study of three different types of plate osteosynthesis on an osteoporotic computational model, Sabalic et al.[26] reported that the parallel plating technique demonstrated the highest stiffness in axial compression, bending and varus loading compared to the perpendicular plating technique. In their study of 14 cadaveric distal humeri with simulated intra-articular fracture with metaphyseal defect comparing parallel and orthogonal plating techniques, Zalavras et al.[27] found that use of parallel plating techniques resulted in significantly higher stiffness during varus cyclic loading, significantly higher ultimate torque in varus loading to failure and higher ultimate load in axial/sagittal loading to failure; therefore, they recommend parallel plating for intra-articular distal humerus fractures with metaphyseal defects. In their study of 34 cadaveric bones comparing biomechanical properties of various plates using 90° double plating for simulated AO type C2 distal humeral fractures, Schuster et al.[6] concluded that the stability of any plating technique was dependent on the bone mineral density, however, with good bone quality the choice of implant was not critical. They also noted that the locking plates provided superior resistance against screw loosening if the bone-mineral density was low (<420 mg/cm^3) compared to the conventional reconstruction plates. Their study also recommends using locking plates for comminution and osteopenic fractures. Caravaggi et al.,[28] in their biomechanical study of 28 cadaveric humeri, noted that significantly higher stiffness to ultimate failure strength and axial loading was demonstrated when using the parallel locking plate technique versus the orthogonal plating technique. Regardless of orientation, locked plate design in either orthogonal or parallel plates performed far better than non-locked plating configurations. In their biomechanical study comparing parallel plating with perpendicular plating using artificial epoxy resin humerus, Arnander et al.[29] reported that the stiffness and strength data of the 2 plating methods were recorded by testing to failure with sagittal plane bending forces; they concluded that the parallel plate showed significantly higher resistance to sagittal plane bending forces compared to the perpendicular plate configuration. The biomechanical comparisons are summarized in Table 1.

Clinical Comparison

Three clinical studies comparing orthogonal and parallel plating techniques have been reported. Shin et al.[30] reported a retrospective study of 38 cases of distal humerus fractures treated using two different methods. Seventeen patients were treated with orthogonal plating (group I) and 18 patients with parallel plating (group II). The arc of flexion in the orthogonal plating group was 106° ± 23° while that for the parallel plating group was 112° ± 19°. Average Mayo Elbow Performance Score

Table 1. Summary of Biomechanical Studies between Orthogonal versus Parallel Plating

Author	Materials	Fracture classification	Plate	Load/stress	Outcome
Schwartz et al.[21]	Epoxy composite humeri	AO C3	LCP	Flexion/extension Axial torsion Axial compression Varus/valgus	No difference Orthogonal>parallel Orthogonal<parallel No difference
Got et al.[22]	10 Cadaveric humeri	AO C3	LCP	Torque to failure Torque to failure Failure to torsion Stiffness of fixation Sensitivity to bone density	Orthogonal>parallel No difference No difference No difference No difference
Stoffel et al.[24]	24 Cadaveric humeri	AO C2	LCP	Compression External rotation Axial deformation Sensitivity to osteopenia	Orthogonal<parallel Orthogonal<parallel Orthogonal<parallel Orthogonal>parallel
Penzkofer et al.[25]	Artificial bone model	AO C2.3	LCP	Extension Flexion	Orthogonal<parallel Orthogonal>parallel
Sabalic et al.[26]	Osteoporotic humeral model	AO A	RP Y plate	Axial compression Bending stress Varus loading	Parallel>orthogonal>Y plate Orthogonal<parallel<Y plate Orthogonal<parallel<Y plate
Zalavras et al.[27]	14 Cadaveric humeri	AO C3	Non-locking plate	Cyclic varus Varus to failure Axial to failure	Orthogonal<parallel Orthogonal<parallel Orthogonal<parallel
Caravaggi et al.[28]	28 Cadaveric humeri	AO type C	LCP	Axial torsion Ultimate failure Sagittal stiffness	Orthogonal<parallel Orthogonal<parallel No difference
Schuster et al.[6]	34 Cadaveric humeri	AO type C2.3	RP LCP DHP	Construct stiffness Cyclic failure rate	No difference DHP<RP<LCP
Arnander et al.[29]	Epoxy resin humeri	AO type C	RP	Sagittal stiffness Sagittal strength	Orthogonal<parallel Orthogonal<parallel

LCP: locking compression plate, RP: reconstruction plate, DHP: distal humeral plate.

(MEPS) score for orthogonal plating was 91.5 (range, 70–100) with 14 patients (82%) showing good or excellent results, while the score for the parallel plating group was 94.3 (range, 70–100) with 16 patients (89%) showing good or excellent results. Regarding complications, there were 29% in group I and 38% in group II. They further concluded that while a higher number of patients in the orthogonal plating group achieved bony union, both plating techniques can provide anatomic restoration and adequate stability of the distal humerus. Likewise, Tian et al.,[31] in a study of 25 patients with AO/OTA type C fractures of the distal humerus, 13 patients were treated using the orthogonal plate (group I) while 12 patients were treated with Y plate (group II). These patients were followed up for 12 to 38 months (19.2 ± 7.1 months). Average MEPS was 84% for group I and 83% for group II with good to excellent scores. As with these results, there was no significant difference in the clinical outcomes between the two plating techniques. Recently, Lee et al.,[32] in a prospective randomized trial between orthogonal and parallel plating methods in 67 patients with AO type C1 to C3 with a minimum follow-up of two years (range, 2–3.7 years), noted no

significant differences in terms of clinical outcomes and complication rates between the two techniques. Flexion arc was 98° ± 20° in the orthogonal group while that in the parallel plating group was 100° ± 23°. MEPS and DASH scores were 85.1 ± 28.2 and 25.2 ± 9.8 for the orthogonal group and 89.7 ± 30.1 and 22.9 ± 8.7 for the parallel plating group, respectively. There were 3 and 2 cases of heterotopic ossification for orthogonal and parallel plating, respectively. The orthogonal plating technique, however, is recommended in cases with coronal shear fractures requiring posterior to anterior fixation to provide additional stability to the intraarticular fractures.

Surgical Techniques

A standard posterior approach is used with or without olecranon osteotomy. Identification, protection, and mobilization of the ulnar nerve is important with this exposure in order to prevent injury and subcutaneous transposition can be performed at the end of the procedure. Once the fracture is properly exposed and articular components are reduced, provisional fixation with
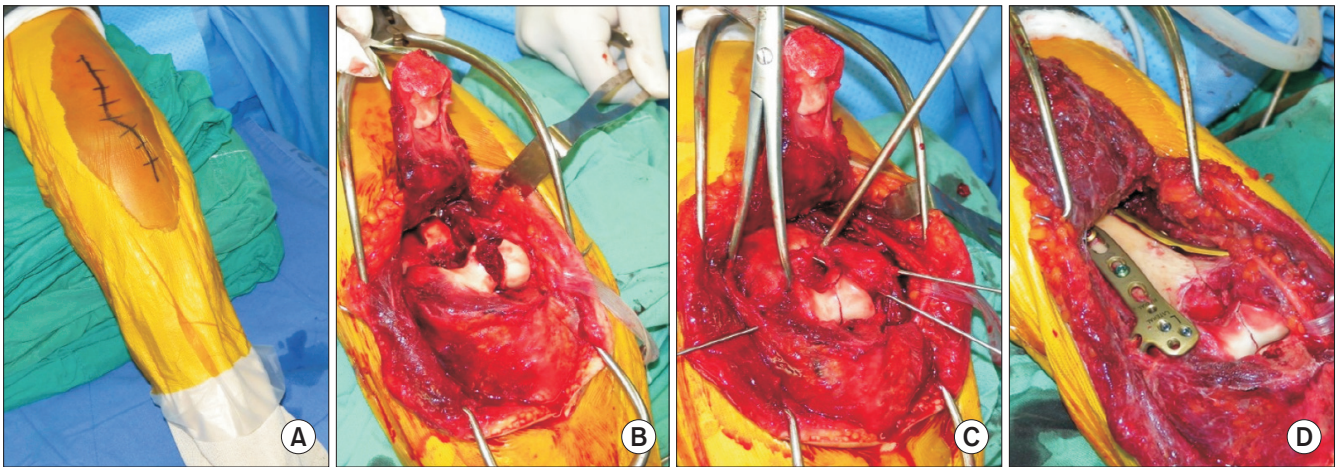
Fig. 3. Surgical techniques of orthogonal plating. (A) Posterior skin incision in the lateral decubitus position. (B) Intraarticular fracture exposure after olecranon osteotomy. (C) Temporary fixation with multiple Kirschner wires and reduction clamps. (D) Final placement of the orthogonal plate.
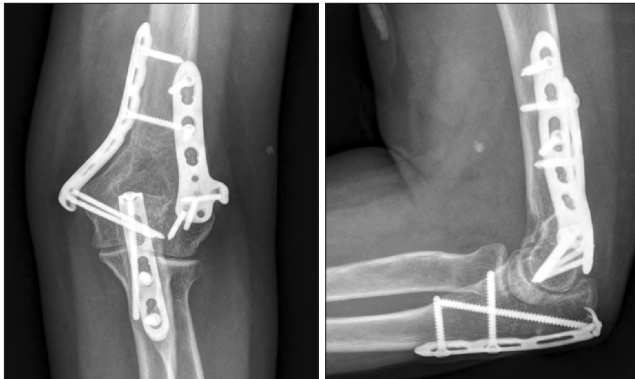

Fig. 4. Postoperative radiographs demonstrating fixation using orthogonal plating.

Kirschner wires and bone clamps can be performed. The temporary reduction is then checked with intraoperative imaging and once confirmed, the plate is then applied to the medial column and lateral or posterolateral column (Fig. 3).

In orthogonal plating, the plate is positioned on the posterolateral surface of the humerus and distally up to the posterior edge of the capitellum. The construct should ideally have at least 3 screws distal and 3 screws proximal to the fracture site in each plate and column. In general, the plate is first applied to the more stable column, which is then partially fixed to the supracondylar area of the humerus; the second plate is then positioned and fixed in place (Fig. 4). Once all screws are placed and the plates are secured to the distal humerus, range of motion is tested to check for sufficient stability and absence of mechanical block. Adequate repair of the triceps is recommended if the approach involved is via the triceps-related techniques. If the approach used was olecranon osteotomy, multiple techniques of fixation on the osteotomy site can be used accordingly.

In parallel plating, initial exposure of the humerus is similar to that with orthogonal plating except more exposure of the lateral column for lateral column plating. This technique is best described by O'Driscoll[20] and Sanchez-Sotelo et al.[33] After thorough exposure and visualization of distal humeral fracture, attention is directed to the articular surface for reassembly and reduction. Provisional reduction of the articular fragments is held in place by Kirschner wires, which should be purchased close to the subchondral bone so as not to interfere during placement of screws from the plates into the distal fragments. The length of the plate should be long enough to allow purchase of 3 screws proximal to the metaphyseal fracture on both the lateral and medial columns of the distal humerus. The plates used should be of different length and end at different levels to prevent formation of a stress riser.[20,33] With selection of the appropriate size and length of the medial and lateral plates, they are provisionally held in place by Kirschner wires, which are driven into the lateral and medial epicondyles through holes in the plates. These pins are left only to be removed later and replaced by screws. Once plate adjustment and appropriate anatomic reduction of the fragments at the supracondylar area to the humeral shaft is achieved, one cortical screw is introduced loosely into the proximal hole of each plate. A large bone clamp is then used to compress the intraarticular fragments together with the plates followed by introduction of 2 distal screws, one each for the medial and lateral plates. These screws should be as long as possible, pass through as many fragments as possible, and engage through the opposite column. Once the two distal screws are purchased and the distal fragments are secured to the plates, focus on the supracondylar region follows. Once the proximal screw on one side is backed out and a large bone tenaculum is placed eccentrically to provide interfragmentary compression across the fracture at the supracondylar level, a second proximal screw is then inserted in compression mode and the initial proximal slotted screw is re-tightened. The coronal and rotational
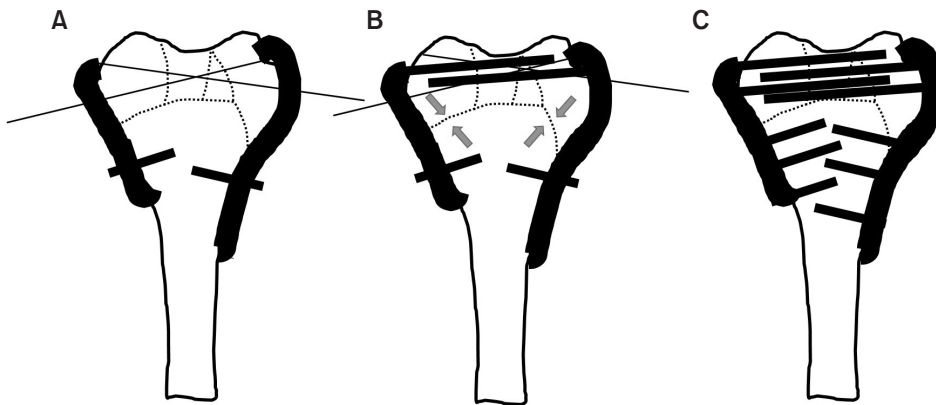
Fig. 5. Surgical techniques of parallel plating. (A) Plate placement and insertion of initial loose proximal screws. (B) Long distal screw placement and compression across the fractures at the supracondylar level. (C) All screws passing through plates lock together.
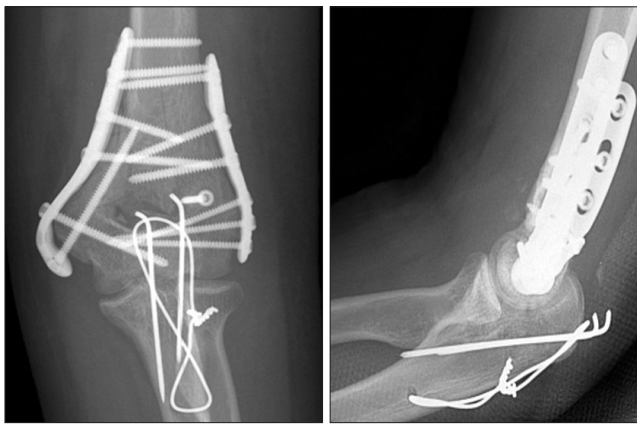

Fig. 6. Postoperative radiographs demonstrating fixation using parallel plating.

the orthogonal plating in cases of coronal plane fractures involving the capitellum and trochlea. Posterior to anterior screw can maintain a stable anatomic articular position. In cases of lower level fractures or osteoporotic fractures, parallel plating is preferred as longer screws can purchase small and weak distal fragments. This advantage of parallel plating was emphasized by some surgeons who questioned inadequate fixation stability with orthogonal plating.[19] However, placing a plate on the lateral side can be technically more difficult and requires more stripping of the soft tissue. Damage to the segmental posterior condylar vessels, supplying the lateral column, can occur during the procedure, increasing risk of delayed union and nonunion.[35]

Summary

Dual plating in distal humerus fractures has been recommended for stable fixation with a new implant and better surgical exposures. Little difference in plating configuration, either orthogonal or parallel, was found in biomechanical analyses and no significant difference with regard to clinical outcomes. Both techniques have shown satisfactory outcomes and their own complications have been reported as well. When to use orthogonal or parallel plating is based on the surgeon's preference. But, decision may depend on fracture pattern and bone quality. Success in treating these fractures starts with preoperative understanding of the normal anatomy and the fracture pattern. Intraoperatively, obtaining an anatomic reduction of the articular surface with a stable hardware construct, which will allow early range of motion while minimizing complications, will surely result in favorable outcomes.

alignments should be maintained in their physiologic state and care should be taken to maintain their alignment during application of the bone clamp (Fig. 5). The reduction of the distal fragment to the supracondylar is then performed on the opposite side in the same manner. The remaining screws for the humeral diaphysis are then inserted to provide additional stability. The Steinman pins initially inserted at the start of the procedure are now removed and replaced with a screw of appropriate length. Once all screws and plates are secured in place, the elbow range of motion is checked to ensure absence of mechanical blockage (Fig. 6).

Postoperatively, a well-padded extension splint is applied and patients are encouraged to keep the arm elevated in order to minimize swelling. After removal of the drain, motion exercises are initiated within the first week after surgery including active assisted and gentle passive motion for elbow flexion/extension and pronation/supination. A night splint and a hinged braced are used for maintenance of gain. Prophylaxis for heterotrophic ossification using medication or radiation is considered.[34]

Although both techniques are commonly used by surgeons and can be indicated in most cases, in some instances one technique might be preferred over another. The authors prefer

References

1. Abzug JM, Dantuluri PK. Use of orthogonal or parallel plating techniques to treat distal humerus fractures. Hand Clin. 2010; 26(3):411-21, vii.
2. Goel DP, Pike JM, Athwal GS. Open reduction and internal fixation of distal humerus fractures. Oper Tech Orthop. 2010;

20(1):24-33.

3. Green A. Surgical treatment of bicolumn distal humeral fractures: relevant anatomy and classification. Instr Course Lect. 2009;58:505-7.

4. Tejwani NC, Murthy A, Park J, McLaurin TM, Egol KA, Kummer FJ. Fixation of extra-articular distal humerus fractures using one locking plate versus two reconstruction plates: a laboratory study. J Trauma. 2009;66(3):795-9.

5. Schemitsch EH, Tencer AF, Henley MB. Biomechanical evaluation of methods of internal fixation of the distal humerus. J Orthop Trauma. 1994;8(6):468-75.

6. Schuster I, Korner J, Arzdorf M, Schwieger K, Diederichs G, Linke B. Mechanical comparison in cadaver specimens of three different 90-degree double-plate osteosyntheses for simulated C2-type distal humerus fractures with varying bone densities. J Orthop Trauma. 2008;22(2):113-20.

7. Wong AS, Baratz ME. Elbow fractures: distal humerus. J Hand Surg Am. 2009;34(1):176-90.

8. Ramsey ML. Surgical exposures for bicolumn distal humeral fractures. Instr Course Lect. 2009;58:509-14.

9. Seigerman DA, Choung EW, Yoon RS, et al. Identification of the radial nerve during the posterior approach to the humerus: a cadaveric study. J Orthop Trauma. 2012;26(4):226-8.

10. Yildirim AO, Oken OF, Unal VS, Esmer AF, Gülçek M, Uçaner A. Avoiding iatrogenic radial nerve injury during humeral fracture surgery: a modified approach to the distal humerus. Acta Orthop Traumatol Turc. 2012;46(1):8-12.

11. McCann PA, Smith GC, Clark D, Amirfeyz R. The tricipital aponeurosis: a reliable soft tissue landmark for humeral plating. Hand Surg. 2015;20(1):53-8.

12. Jupiter JB, Neff U, Holzach P, Allgöwer M. Intercondylar fractures of the humerus. An operative approach. J Bone Joint Surg Am. 1985;67(2):226-39.

13. Korner J, Diederichs G, Arzdorf M, et al. A biomechanical evaluation of methods of distal humerus fracture fixation using locking compression plates versus conventional reconstruction plates. J Orthop Trauma. 2004;18(5):286-93.

14. Helfet DL, Schmeling GJ. Bicondylar intraarticular fractures of the distal humerus in adults. Clin Orthop Relat Res. 1993; (292):26-36.

15. Henley MB, Bone LB, Parker B. Operative management of intra-articular fractures of the distal humerus. J Orthop Trauma. 1987;1(1):24-35.

16. Holdsworth BJ, Mossad MM. Fractures of the adult distal humerus. Elbow function after internal fixation. J Bone Joint Surg Br. 1990;72(3):362-5.

17. Letsch R, Schmit-Neuerburg KP, Stürmer KM, Walz M. Intraarticular fractures of the distal humerus. Surgical treatment and results. Clin Orthop Relat Res. 1989;(241):238-44.

18. Sanchez-Sotelo J, Torchia ME, O'Driscoll SW. Complex distal humeral fractures: internal fixation with a principle-based parallel-plate technique. J Bone Joint Surg Am. 2007;89(5):961-9.

19. O'Driscoll SW. Optimizing stability in distal humeral fracture fixation. J Shoulder Elbow Surg. 2005;14(1 Suppl S):186S-94.

20. O'Driscoll SW. Parallel plate fixation of bicolumn distal humeral fractures. Instr Course Lect. 2009;58:521-8.

21. Schwartz A, Oka R, Odell T, Mahar A. Biomechanical comparison of two different periarticular plating systems for stabilization of complex distal humerus fractures. Clin Biomech (Bristol, Avon). 2006;21(9):950-5.

22. Got C, Shuck J, Biercevicz A, et al. Biomechanical comparison of parallel versus 90-90 plating of bicolumn distal humerus fractures with intra-articular comminution. J Hand Surg Am. 2012;37(12):2512-8.

23. Self J, Viegas SF, Buford WL Jr, Patterson RM. A comparison of double-plate fixation methods for complex distal humerus fractures. J Shoulder Elbow Surg. 1995;4(1 Pt 1):10-6.

24. Stoffel K, Cunneen S, Morgan R, Nicholls R, Stachowiak G. Comparative stability of perpendicular versus parallel double-locking plating systems in osteoporotic comminuted distal humerus fractures. J Orthop Res. 2008;26(6):778-84.

25. Penzkofer R, Hungerer S, Wipf F, von Oldenburg G, Augat P. Anatomical plate configuration affects mechanical performance in distal humerus fractures. Clin Biomech (Bristol, Avon). 2010;25(10):972-8.

26. Sabalic S, Kodvanj J, Pavic A. Comparative study of three models of extra-articular distal humerus fracture osteosynthesis using the finite element method on an osteoporotic computational model. Injury. 2013;44 Suppl 3:S56-61.

27. Zalavras CG, Vercillo MT, Jun BJ, Otarodifard K, Itamura JM, Lee TQ. Biomechanical evaluation of parallel versus orthogonal plate fixation of intra-articular distal humerus fractures. J Shoulder Elbow Surg. 2011;20(1):12-20.

28. Caravaggi P, Laratta JL, Yoon RS, et al. Internal fixation of the distal humerus: a comprehensive biomechanical study evaluating current fixation techniques. J Orthop Trauma. 2014;28(4):222-6.

29. Arnander MW, Reeves A, MacLeod IA, Pinto TM, Khaleel A. A biomechanical comparison of plate configuration in distal humerus fractures. J Orthop Trauma. 2008;22(5):332-6.

30. Shin SJ, Sohn HS, Do NH. A clinical comparison of two different double plating methods for intraarticular distal humerus fractures. J Shoulder Elbow Surg. 2010;19(1):2-9.

31. Tian D, Jing J, Qian J, Li J. Comparison of two different double-plate fixation methods with olecranon osteotomy for intercondylar fractures of the distal humeri of young adults. Exp Ther Med. 2013;6(1):147-51.

32. Lee SK, Kim KJ, Park KH, Choy WS. A comparison between orthogonal and parallel plating methods for distal humerus fractures: a prospective randomized trial. Eur J Orthop Surg Traumatol. 2014;24(7):1123-31.

33. Sanchez-Sotelo J, Torchia ME, O'Driscoll SW. Complex distal

humeral fractures: internal fixation with a principle-based parallel-plate technique. Surgical technique. J Bone Joint Surg Am. 2008;90 Suppl 2 Pt 1:31-46.

34. Green A. Postoperative management after open reduction and internal fixation of distal humeral fractures. Instr Course Lect. 2009;58:535-9.

35. Kimball JP, Glowczewskie F, Wright TW. Intraosseous blood supply to the distal humerus. J Hand Surg Am. 2007;32(5): 642-6.