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Complex Distal Humeral Fractures: Internal Fixation with a Principle-Based Parallel-Plate Technique

Surgical Technique

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ABSTRACT FROM THE ORIGINAL ARTICLE

BACKGROUND: Severe comminution, bone loss, and osteopenia at the site of a distal humeral fracture increase the risk of an unsatisfactory result, often secondary to inadequate fixation. The purpose of this study was to determine the outcome of treating these fractures with a principle-based technique that maximizes fixation in the articular fragments and stability at the supracondylar level.

METHODS: Thirty-four consecutive complex distal humeral fractures were fixed with two parallel plates applied (medially and laterally) in approximately the sagittal plane. The technique was specifically designed to satisfy two principles: (1) fixation in the distal fragments should be maximized and (2) screw fixation in the distal segment should contribute to stability at the supracondylar level. Twenty-six fractures were AO type C3, and fourteen were open. Thirty-two fractures were followed for a mean of two years. The patients were assessed clinically with use of the Mayo Elbow Performance Score (MEPS) and radiographically.

RESULTS: Neither hardware failure nor fracture displacement occurred in any patient. Union of thirty-one of the thirty-two fractures was achieved primarily. Five patients underwent additional surgery to treat elbow stiffness. There was one deep infection that resolved without hardware removal and did not impede union. At the time of the most recent follow-up, twenty-eight elbows were either not painful or only mildly painful, and the mean flexion-extension arc was 99°. The mean MEPS was 85 points. The result was graded as excellent for eleven elbows, good for sixteen, fair for two, and poor for three.

CONCLUSIONS: Stable fixation and a high rate of union of complex distal humeral fractures can be achieved when a principle-based surgical technique that maximizes fixation in the distal segments and stability at the supracondylar level is employed. The early stability achieved with this technique permits intensive rehabilitation to restore elbow motion.

LEVEL OF EVIDENCE: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.


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INTRODUCTION
Severe comminution, bone loss, and osteopenia predispose distal humeral fractures to unsatisfactory results due to inadequate fixation. Poor outcomes include contracture, secondary to prolonged immobilization thought to be necessary to protect the fixation, and nonunion. In an effort to reproducibly obtain stable fixation in the presence of osteoporosis or comminution, we have developed an improved fixation technique for fractures of the distal part of the humerus based on principles that enhance fixation in the distal fragments and provide compression at the supracondylar level. The key to the stability achieved with this fixation construct is that it combines the features and stability of an arch while locking the two columns of the distal part of the humerus together.

SURGICAL TECHNIQUE
Exposure
The operation is performed with the patient in the supine position. A sterile tourniquet is inflated only for dissection of the ulnar nerve, which is transposed anteriorly. The TRAP (triceps-anconeus reflecting...
pedicle) approach provides adequate exposure for a surgeon experienced with the technique. This approach involves combining the Bryan-Morrey and modified Kocher approaches to reflect the triceps in continuity with the anconeus. However, we believe that an olecranon osteotomy provides even greater exposure and it is recommended in the setting of intra-articular comminution.

**Principle-Based Fixation Technique**

We attempt to restore stability and function by achieving eight technical objectives derived from the principles of (1) maximizing fixation in the distal fragments and (2) ensuring that all fixation in the distal segment contributes to stability at the supracondylar level. Six of these objectives concern the screws in the distal fragments, and two concern the plates (Table I) (Fig. 1).

All eight of these objectives are achieved with the technique of what we term parallel plating. The medial plate is placed...
on the medial aspect of the medial column, and the lateral plate is placed laterally, rather than posteriorly, on the lateral column. While we refer to the plates as being parallel, each plate is actually rotated posteriorly slightly out of the sagittal plane such that the angle between them is often in the range of 150° to 160°. This orientation permits the insertion of at least four long screws completely through the distal fragments from one side to the other. These screws interdigitate, thereby creating a fixed-angle structure and greatly increasing stability of the construct. Contact between screws is intended to enhance the locking together of the two columns. The plates must be contoured to fit the geometry of the distal part of the humerus if precontoured plates are not available. Locking screws were not used in this series.

Interfragmentary compression is obtained between articular fragments as well as at the metaphyseal level through the use of large bone clamps that provide compression during the insertion of the screws attaching the articular segment to the shaft. In the distal fragments, fully-threaded screws inserted in this manner provide maximum thread purchase in the distal

FIG. 3

Step 2: Plate application and provisional fixation. Medial and lateral precontoured plates are placed and are held apposed to the distal part of the humerus while one smooth 2 or 2.5-mm Steinmann pin is inserted through hole #2 (numbered from distal to proximal) of each plate, through the epicondyles, and across the distal fragments, to maintain provisional fixation of the plates to the distal fragments. A screw is placed in the slotted hole (hole #5) of each plate but is not fully tightened, leaving some freedom for the plate to move proximally later during compression. Because the undersurface of each plate is tubular in the metaphyseal and diaphyseal regions, the screw in the slotted hole only needs to be tightened slightly to provide excellent provisional fixation of the entire distal part of the humerus.
### Table I Technical Objectives Checklist

Objectives concerning screws in the distal fragments (articular segment)

- **Objective 1:** Each screw should pass through a plate
- **Objective 2:** Each screw should engage a fragment on the opposite side that is also fixed to a plate
- **Objective 3:** An adequate number of screws should be placed in the distal fragments
- **Objective 4:** Each screw should be as long as possible
- **Objective 5:** Each screw should engage as many articular fragments as possible
- **Objective 6:** The screws should lock together by interdigitation, thereby creating a fixed-angle structure and linking the columns together

Objectives concerning the plates used for fixation

- **Objective 7:** Plates should be applied such that compression is achieved at the supracondylar level for both columns
- **Objective 8:** Plates used must be strong enough and stiff enough to resist breaking or bending before union occurs at the supracondylar level

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**Step 3: Articular fixation.** Screws are inserted through hole #1 of the lateral plate and across the distal articular fragments, from lateral to medial, and are tightened. This step is repeated on the medial side with use of hole #3. In young patients, 3.5-mm cortical screws are used (to prevent breakage), whereas in patients with osteoporotic bone, long 2.7-mm screws are used. The distal screws should be as long as possible, should pass through as many fragments as possible, and should engage the condyle or epicondyle of the opposite column.
fragments. Additional compression at the metaphyseal level results from slight under-contouring of the plates and the use of dynamic compression holes in the plates. The specific steps of the surgical technique are detailed below.

**Step 1. Articular Surface Reduction (Fig. 2)**

Once the fracture is exposed, the first step is reassembly of the articular surface. The proximal part of the ulna and the radial head can be used as a template for the reconstruction of the distal part of the humerus. The articular fragments are provisionally fixed with smooth Kirschner wires (Fig. 2). In cases in which there is extensive comminution, fine threaded wires (1 to 1.5 mm) are used and then are cut off and left in as definitive adjunctive fixation. Kirschner wires permit assembly of the joint surface fragments in a manner that is analogous to the use of dowels in furniture making. It is necessary for these wires to be placed close to the subchondral level so as not to interfere with the passage of screws from the plates into the distal fragments; specifically, no...
screws are placed in the distal fragments until the plates are applied.

The articular surface of the distal part of the humerus should be reconstructed anatomically unless bone is missing. In the event of absent bone, two important principles should be taken into consideration. First, the anterior aspect of the distal part of the humerus is the critical region that needs to be restored in order to have a functional joint; reconstruction of the posterior articular surface of the distal part of the humerus is less critical. Second, stability of the articulation requires the presence of the medial half of the trochlea in combination with either the lateral half of the trochlea or the capitellum; thus, the medial half of the trochlea is essential for obtaining a stable and well-aligned joint.

Step 2. Plate Placement and Provisional Fixation (Fig. 3)
The next step is to contour plates to fit the reasssembled humerus medially and laterally or to choose medial and lateral precontoured
Step 5: Final fixation. The smooth Steinmann pins are all removed, and the remainder of the screws are inserted. The distal screws interdigitate for maximum fixation in the distal articular fragments (as described in the legend to Figure 1).

FIG. 6

FIG. 7

In cases of supracondylar bone loss, and in some cases of severe comminution, anatomic placement of the distal part of the humerus with respect to the shaft would leave a large structural defect in the metaphysis in one column and only point contact in the other. In cases in which structural bone graft is not an option, a supracondylar shortening osteotomy can be performed. A, This involves reshaping the distal end of the shaft (dark lines) (never the articular segments) to enhance contact between the distal articular segment and the shaft. Usually, only a small amount of bone is resected from the distal end of the shaft, and sometimes from one side of it as well (for side-to-side apposition and compression). B and C, The limb is shortened through the fracture site to permit interfragmentary compression between the trochlea and the distal part of the shaft, between the capitellum and the distal part of the shaft, and from side to side on one side. Once these surfaces have been compressed and fixed with the plates, stability is strong enough to permit immediate motion and rehabilitation. It is acceptable to translate the distal segment medially or laterally, and also slightly anteriorly, provided that rotational and valgus alignment is maintained. (With permission of the Mayo Foundation.)
Low transcondylar fractures through osteopenic bone (Figs. 8-A and 8-B) require placement of the plates distal enough to allow secure fixation. Excellent stability can still be obtained with the technique of parallel plating, employing a medial plate that is contoured around the epicondyle onto the medial side of the trochlea along with a lateral plate (Figs. 8-C and 8-D).
plates; one-third tubular plates are not strong enough for fixation of these complex fractures. The medial plate can be extended to the articular margin in cases of very distal or comminuted fractures and is contoured to the shape of the medial epicondyle. The ulnar nerve must be transposed if this extended plate is used. Both plates should be slightly undercontoured to provide additional compression at the metaphyseal region when applied. The length of the plates is selected so that at least three screws can be placed in the proximal part of the humeral shaft both medially and laterally proximal to the metaphyseal component of the fracture. Ideally, the plates should end at different levels proximally to avoid the creation of a stress-riser. The plates are then provisionally applied according to the following steps.

First, two smooth 2.0 to 2.5-mm Steinmann pins are introduced at the medial and lateral epicondyles through holes in the plates while they are held accurately against the bone. These pins are left in place until after step 4 (described below). The pins create pilot holes for later replacement with screws, are easy to drill around, and do not interfere as much with the placement of the two distal screws as would be the case if they were replaced by screws earlier.

Second, the appropriate
reduction of the distal fragments to the humeral shaft at the supracondylar level is confirmed.

Third, one cortical screw is loosely introduced into a slotted hole to secure each plate in place; the use of slotted holes facilitates later adjustments in plate position.

**Step 3. Articular Fixation (Fig. 4)**
Once the plates have been provisionally applied, medial and lateral screws are introduced distally to provide stable fixation of the intra-articular fragments and rigid anchorage to the plates. The two distal screws, one medial and one lateral, are inserted with use of a targeted drill-guide. As stated above, the screws should be as long as possible, should pass through as many fragments as possible, and should engage in the opposite column. Prior to screw insertion, a large bone clamp is used to compress the intra-articular fracture lines unless there is a gap in the articular surface. This ensures interfragmentary compression without the need for lag screws.

**Step 4. Supracondylar Compression (Figs. 5-A and 5-B)**
The plates are then fixed proximally under maximum compression at the supracondylar level.

First, the slotted proximal screw on one side is backed out and a large bone clamp is applied distally on that side and proximally on the opposite cortex to eccentrically load the supracondylar region. A second proximal screw is inserted through the plate in compression mode, and then the screw in the slotted hole is retightened. Care should be taken not to change the varus-valgus or rotational alignment of the articular surface when the
bone clamps are applied. Second, the same steps are followed on the opposite side. Following this step, the fixation should be quite stable.

Third, diaphyseal screws are then introduced, providing additional compression as a result of the undercontoured plates being pulled down to the underlying bone. To avoid having the screws strip the bone, this last step is best performed by squeezing the plates against the bone with a large clamp rather than relying on the screws to deform the plates.

**Step 5. Final Fixation (Fig. 6)**
The smooth Steinmann pins are removed, and the remainder of the screws are inserted. The intraoperative elbow motion should be full unless substantial swelling has already developed. One deep and one subcutaneous drain are placed during the closure. The skin should be closed with staples or interrupted sutures.

**Dealing with Metaphyseal Bone Loss**
Adequate osseous contact with interfragmentary compression in the supracondylar region is necessary to ensure the stability of the construct and eventual fracture union. If metaphyseal bone loss or comminution precludes an anatomic reconstruction with satisfactory osseous contact, the humerus can be shortened at the metaphyseal-diaphyseal fracture site, provided that the overall alignment and geometry of the distal part of the humerus is correct. We refer to this alternative reconstructive technique as supracondylar shortening (Fig. 7). This technique is especially useful in cases of combined soft-tissue and bone loss. Shortening by ≤1 cm has only a slight effect on triceps strength in terminal extension, and in cases of severe soft-tissue and bone loss, as much as 2 cm of shortening can be tolerated without serious disturbance of elbow biomechanics.

**POSTOPERATIVE MANAGEMENT**
Immediately after wound closure, the elbow is placed in a bulky noncompressive Jones dressing with an anterior plaster...
slab to maintain full extension, and the upper extremity is kept elevated. The initial rehabilitation is planned according to the extent of soft-tissue damage. Fractures that are associated with severe soft-tissue damage, which include most open fractures and high-energy closed fractures, are immobilized and elevated in elbow extension for three to seven days postoperatively. Closed fractures without severe swelling or fracture blisters are removed from the Jones dressing after two days, and a nonconstrictive elastic sleeve is applied over an absorbent dressing that is placed on the wound. A physical therapy program that includes active and passive motion is then initiated. All patients are permitted active use of the hand and are instructed not to lift (or pull or push) anything heavier than a glass of water or a telephone receiver for the first six weeks. No form of external protection such as casts or braces is used.

If postoperative motion fails to progress as expected, a program of patient-adjusted static splinting is instituted as soon as the soft tissues are healed. Eight of the elbows in this study were treated with such a program, which was commenced after the third or fourth week. The torque across the elbow that was applied with such a patient-adjusted splint was low enough to cause discomfort but not pain and therefore was not of concern with regard to the security of the fracture fixation.

Neither hardware failure nor fracture displacement occurred in any patient, and primary union was achieved at the sites of thirty-one of thirty-two fractures.
Figs. 9-C and 9-D Fine threaded Kirschner wires, fully embedded in the bone, were used to assemble the articular fragments just as dowels are used when pieces of wood are glued together to make furniture.
CRITICAL CONCEPTS

The critical concept being presented here is the idea that stability of the distal part of the humerus is achieved by the creation of an architectural structure. The bone fragments rely on their integration with the structure, rather than on fixation by screw threads, for stability. The concept is borrowed from architectural concepts and the application of civil engineering principles to surgery. The interdigitation of screws within the distal segment rigidly attaches the articular fragments to the shaft by linking the two columns together. This permits stability to be achieved in cases of injuries such as low transcondylar fractures (Figs. 8-A through 8-D) or severely comminuted fractures (Figs. 9-A through 9-D).

The concept follows the architectural principles of an arch, in which two columns are anchored at their base (on the shaft of the humerus) and are linked together at the top (long screws from the plates on each side interdigitating within the articular segment). The interdigitation is best achieved by contact between the screws. However, multiple screws separated by small gaps within the bone will function as a "rebar" (steel rods inside concrete)-type construct. Fixation of the bone fragments is thus reliant not on screw purchase in the bone but on the stability of the hardware framework, in just the same way in which a modern building derives its stability from the gridwork of steel assembled and bolted or welded together inside its walls and columns.

The screws in the distal segment are converted into fixed-angle screws by two of the technical objectives. First, several long screws in the distal fragments lock together by means of interdigitation. Second, these screws pass through a plate on one side and into a bone fragment on the other side that is itself also anchored by a plate. From an engineering perspective, this technique of creating fixed-angle screws enhances fixation in the distal fragments. It also permits rigid linkage and compression between the distal segment and the shaft. The combined use of clamps, strong and slightly undercontoured plates, dynamic compression holes, and selected metaphyseal shortening provides interfragmentary compression at the supracondylar level. The stability of the construct is such that a rehabilitation program can be commenced in the immediate postoperative period without fear of hardware failure.

INDICATIONS:
The indications for parallel-plate fixation include intercondylar and supracondylar fractures and nonunions of the distal part of the humerus, particularly those that are associated with comminution and/or bone loss. This technique can also be used to fix distal humeral osteotomies.

CONTRAINDICATIONS:
Provided that there are no contraindications to internal fixation or surgery on the elbow in general, we have not experienced specific contraindications to the use of the parallel plating technique for the treatment of distal humeral fractures or nonunions.

PITFALLS:
One pitfall to avoid is the placement of a free screw into the distal fragments prior to the application of a plate. Such a screw does not contribute to supracondylar stability (principle 2) and is not as secure as it might have been if it had passed through a plate (principle 1). It also potentially interferes with the passage of the screws through the plate into the distal articular segment. Another pitfall is the inappropriate placement of Kirschner wires for provisional fixation. These wires should be placed in the subchondral region rather than in the center of the articular segments where the screws will go. They also need to be placed where they will not interfere with the plates. Anticipating where the plates will be positioned on the bone before placing the temporary Kirschner wires avoids this problem. Some surgeons experience difficulty with placement of the distal articular screws through the plates and across to the other side without violating the joint or the olecranon fossa. This maneuver is facilitated by the use of a targeted drill-guide and by waiting to replace the 2 or 2.5-mm Steinmann pins in the distal articular segments until after having placed at least one screw through a second hole of each plate. These pins reserve a pathway for screws to be placed across the distal segment from each side. They also are easy to drill past and to place a screw past, whereas if they are replaced by screws immediately, the

continued
CRITICAL CONCEPTS (continued)

subsequent drilling is rendered more difficult by the larger-diameter screw. Moreover, when drilling through the distal segment, a drill-bit may be prone to hitting a screw and breaking. This problem can be avoided by drilling backward or by drilling with a smooth Steinmann pin; the pin will tend to deflect off a screw rather than break.

With respect to the soft tissues, a common pitfall and misunderstanding is the assumption that the technique of parallel plating requires additional soft-tissue stripping. While the lateral skin flap must be raised around to the lateral supracondylar ridge and the lateral epicondyly, there is no additional stripping of the deep soft tissues from the lateral column compared with traditional plating of a distal humeral fracture. In all circumstances, the soft tissues should be retained on the articular fragments.

Excessive contouring of the distal end of the lateral plate can cause entrapment of the common extensor origin and/or lateral collateral ligament complex. This can result in loss of motion and even necrosis of the underlying soft tissues. This is avoided by placing the plate such that it stops at the epicondyle rather than distal to it and by ensuring that the plate does not wrap around the epicondyle and compress the soft tissues. This will give the appearance on the postoperative radiograph of the tip of the plate sitting away from the bone, but this space is required to accommodate the soft tissues under the plate.

AUTHOR UPDATE:

Subsequent to the publication of the original article, a few changes have been made. We now routinely use precontoured plates rather than bending generic plates. While locking plates are available, we prefer to use variable-angle locking screws for the distal segment to prevent the problem of incorrect screw positioning due to the fixed angles predetermined by plate design. With the use of locking screws, fewer screws are likely to be necessary, and we routinely place four locking screws (two from each side) in the distal segment.

Finally, we have come to believe that resting the soft tissues for a minimum of three days after surgery decreases the physiologic response to trauma compared with starting mobilization one or two days after surgery. Therefore, we place the arm in a padded Jones dressing with an anterior plaster slab to maintain the elbow elevated in an extended position for three days after surgery. It is taken down from the elevated position once or twice an hour for a few minutes to relieve the shoulder and to prevent perfusion disturbance.

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