# Selected Instructional Course Lectures

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# The Unstable Elbow*†

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## Biomechanics of Elbow Dislocation

### *Pathoanatomy*

The pathoanatomy of an elbow dislocation can be thought of as a disruption of the circle of soft tissue or bone, or both, that begins on the lateral side of the elbow and progresses to the medial side in three stages (Fig. 1-A). In stage 1, the lateral collateral ligament is partially or completely disrupted (the ulnar part is disrupted). This disruption results in posterolateral rotatory subluxation of the elbow, which can reduce spontaneously (Fig. 1-B). Stage 2 involves additional disruption anteriorly and posteriorly. There is an incomplete posterolateral dislocation of the elbow in which the concave medial edge of the ulna rests on the trochlea. On a lateral radiograph of the elbow, the coronoid process appears to be perched on the trochlea. This dislocation can be reduced with use of minimal force or by the patient manipulating his or her own elbow. Stage 3 is subdivided into three parts. In stage 3A, all of the soft tissues around and including the posterior part of the medial collateral ligament are disrupted, leaving only the important anterior band (the anterior medial collateral ligament) intact. This permits posterior dislocation by a posterolateral rotatory mechanism. The elbow pivots on the intact anterior band of the medial collateral ligament. Reduction is accomplished by gentle manipulation of the elbow beginning with supination and valgus stress, temporarily recreating the deformity, followed by application of traction, varus stress, and pronation simultaneously. The intact anterior medial collateral ligament provides stability if the forearm is kept in pronation to prevent posterolateral rotatory subluxation during valgus stress-testing. Stage-3A instability is most commonly seen in the presence of fractures of the radial head and coronoid process. In stage 3B, the entire medial collateral complex is disrupted. Varus, valgus, and rotatory instability are all present following reduction. In stage 3C, the instability is so severe that the elbow can dislocate even when it is immobilized in a cast in 90 degrees of flexion. This degree of instability occurs because the entire distal aspect of the humerus has been stripped of soft tissues. Usually, reduction can be maintained only by flexing the elbow beyond 90 degrees to 110 degrees. The flexor-pronator and common extensor muscle origins are important secondary stabilizers of the elbow. These pathoanatomical stages all correlate with clinical degrees of elbow instability. Most commonly, elbow dislocations involve disruption of both the medial and the lateral collateral ligament and, therefore, are at least stage 2[1-3].

Thus, dislocation is the final stage of three sequential stages of elbow instability resulting from posterolateral ulnohumeral rotatory subluxation, with soft-tissue disruption that progresses from the lateral to the medial side. This finding has been confirmed in a study of cadaveric elbows[37]. Twelve of thirteen elbows could be dislocated posteriorly with the anterior medial collateral ligament intact. In each stage, the pathoanatomy correlated with the pattern and degree of instability.

This circle of disruption is referred to as the Horii circle and is analogous to the Mayfield spiral of soft tissue or osseous disruption, or both, in carpal instability (Fig. 1-A). As disruption progresses from the lateral to the medial side, it may pass through the soft tissues or bone, or both. Therefore, an elbow dislocation is most commonly associated with a torn capsule,

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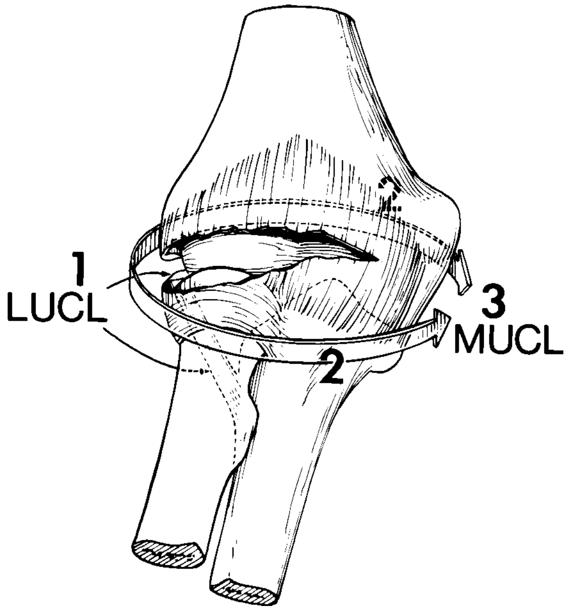


FIG. 1-A

Drawing of the Horii circle of soft-issue injury. The injury progresses from the lateral to the medial side in three stages. In stage 1, the ulnar part of the lateral collateral ligament, the lateral ulnar collateral ligament (LUCL), is disrupted. In stage 2, the other lateral ligamentous structures and the anterior and posterior aspects of the capsule are disrupted. In stage 3, the medial ulnar collateral ligament (MUCL) is either partially disrupted, involving the posterior medial ulnar collateral ligament only (stage 3A), or completely disrupted (stage 3B). The common extensor and flexor origins are often disrupted as well. (Reprinted, with permission, from: O'Driscoll, S. W.; Morrey, B. F.; Korinek, S.; and An, K.-N.: Elbow subluxation and dislocation. A spectrum of instability. Clin. Orthop., 280: 194, 1992.)

but the capsule may be intact if the coronoid process is fractured. Because energy is dissipated with a fracture before the elbow dislocates, the anterior bundle of the medial collateral ligament is often intact when the radial head and coronoid process are both fractured.

This parallel between the pathoanatomy and the degree of displacement explains the spectrum of instability, ranging from posterolateral rotatory instability to posterior dislocation with or without disruption of the anterior medial collateral ligament. Such a posterolateral rotatory mechanism for dislocation would be compatible with those suggested in the 1960s by Osborne and Cotterill[4] and by Roberts[5].

*Constraints to Elbow Instability*

The elbow has both static and dynamic constraints, which are analogous to the defenses of a fortress (Fig. 2). The three primary static constraints to elbow instability are the ulnohumeral articulation, the medial collateral ligament, and the lateral collateral ligament, especially the ulnar part of the lateral collateral ligament (also referred to as the lateral ulnar collateral ligament). The secondary constraints include the radial head, the common flexor and extensor origins, and the capsule. The dynamic stabilizers include the muscles that cross the elbow joint and produce compressive forces at the articulation. The anconeus, triceps, and brachialis are the most important muscles in this regard. Originating near the lateral epicondyle and inserting broadly on the ulna in a fan shape, the anconeus seems designed to serve its major function as a dynamic stabilizer, preventing posterolateral rotational displacement of the elbow. (A word of caution: the nerve to the anconeus, which enters the muscle proximally, is divided with the traditional olecranon osteotomy for distal humeral fractures.)

An elbow with its three primary constraints intact will be stable. If the coronoid process is fractured or

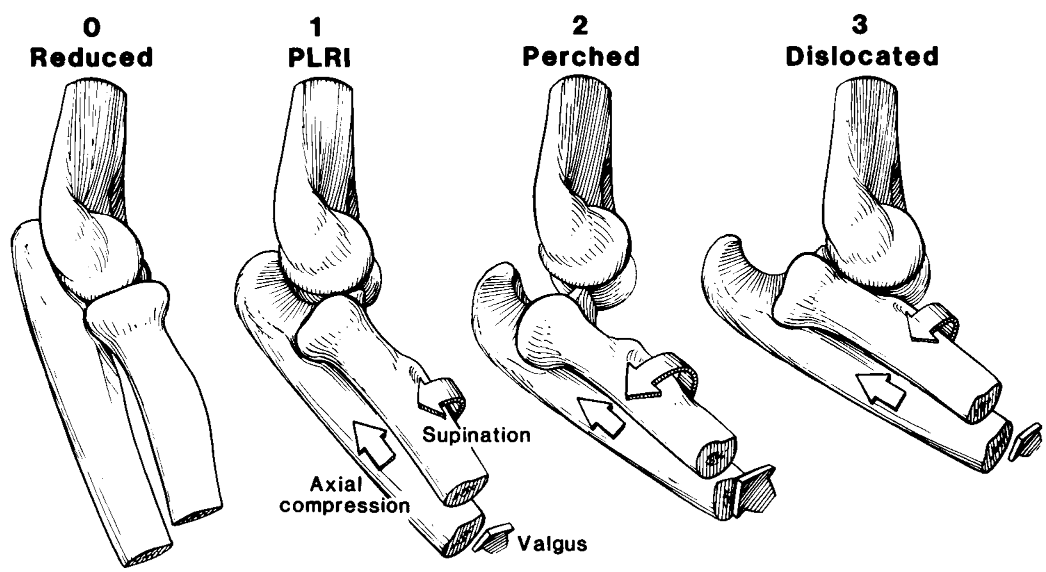


FIG. 1-B

Drawings showing the spectrum of elbow instability, from subluxation to dislocation. The three stages correspond with the pathoanatomical stages of capsuloligamentous disruption in Fig. 1-A. The arrows indicate the forces and moments responsible for displacements. PLRI = posterolateral rotatory instability. (Reprinted, with permission, from: O'Driscoll, S. W.; Morrey, B. F.; Korinek, S.; and An, K.-N.: Elbow subluxation and dislocation. A spectrum of instability. Clin. Orthop., 280: 195, 1992.)

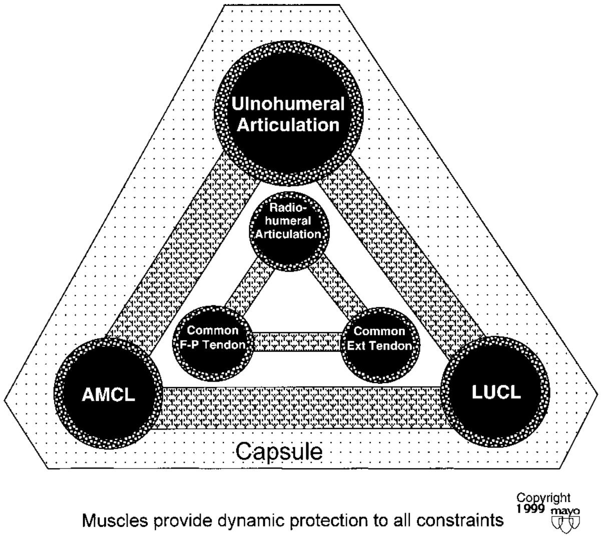


FIG. 2

Illustration showing the static and dynamic constraints to instability, which can be considered analogous to the defenses of a fortress. The three primary static constraints to elbow instability are the ulnohumeral articulation, the anterior medial collateral ligament (AMCL), and the lateral collateral ligament, especially the ulnar part of the lateral collateral ligament, which is also referred to as the lateral ulnar collateral ligament (LUCL). The secondary constraints include the radial head, the common flexor and extensor tendon origins, and the capsule. Dynamic stabilizers include the muscles that cross the elbow joint and produce compressive forces at the articulation. F-P = flexor-pronator.

lost, the radial head becomes a critical stabilizer. The radial head must not be removed when a dislocated elbow is associated with a fractured coronoid process unless the coronoid process and the ligaments can be securely fixed. The management of injuries to these structures is discussed in the ensuing sections.

### *Classification of Elbow Instability*

Elbow instability can be classified into different types according to five criteria: (1) the articulation or articulations involved (the elbow or the radial head), (2) the direction of displacement (valgus, varus, anterior, or posterolateral rotatory), (3) the degree of displacement (subluxation or dislocation), (4) the timing (acute, chronic, or recurrent), and (5) the presence or absence of associated fractures[6].

As described in detail in the section on pathoanatomy, elbow instability can be considered a spectrum consisting of three stages (Fig. 1-B). In stage 1, the elbow subluxates in a posterolateral direction and the patient has a positive lateral pivot-shift test (Fig. 3). In stage 2, the elbow dislocates incompletely so that the coronoid process is perched on the trochlea. In stage 3, the elbow dislocates fully so that the coronoid process rests behind the humerus. Stage 3 is subclassified into three categories. In Stage 3A, the anterior band of the medial collateral ligament is intact and the elbow is stable to valgus stress following reduction. In Stage 3B, the elbow dislocates fully and the anterior band of the medial collateral ligament is disrupted so that the elbow is unstable in varus, valgus, and posterolateral rotation. Some flexion (30 to 45 degrees) is usually required to prevent subluxation. In Stage 3C, the entire distal aspect of the humerus is stripped of soft tissues, rendering the elbow

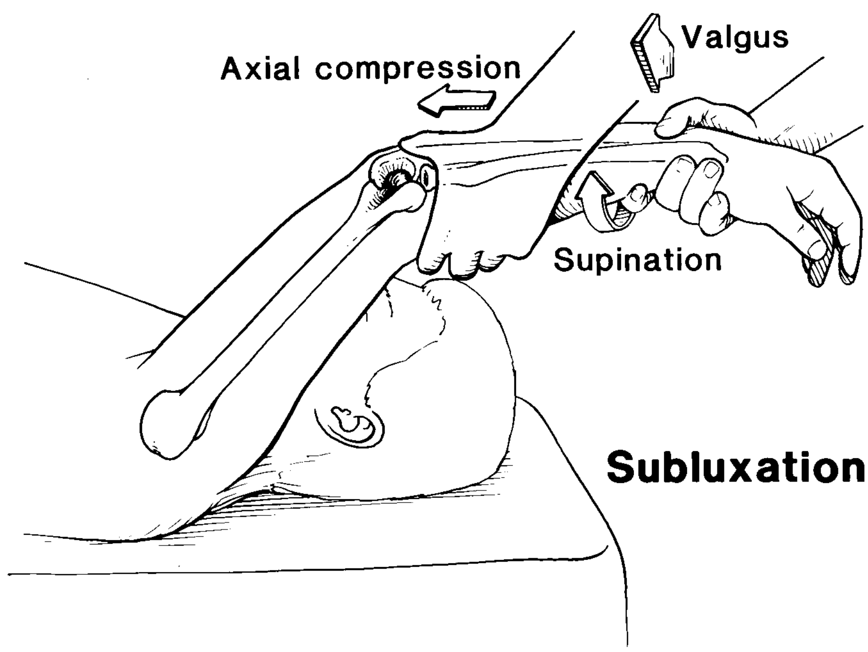


FIG. 3

Illustration showing the lateral pivot-shift test for posterolateral rotatory instability of the elbow, which is performed with the patient's arm overhead. A supination-valgus moment is applied during flexion, causing the elbow to subluxate maximally at about 40 degrees of flexion. Additional flexion causes reduction (with a palpable, visible clunk, if successful). This test creates apprehension in the patient, who notes the sensation that the elbow is about to dislocate.

unstable even in a cast. Reduction can be maintained usually only by flexing the elbow more than 90 degrees. Each stage has specific clinical, radiographic, and pathological features that are predictable and have implications for treatment. The pathological characteristics can be predicted from the degree of instability.

## Evaluation of Acute Dislocations and Fracture-Dislocations

### *Acute Elbow Dislocations*

Dislocated elbows must be evaluated for functional stability after reduction of the dislocation. Following reduction, instability is assessed by gently moving the elbow through a range of motion. If the elbow appears to subluxate or dislocate, a splint is applied and anteroposterior and lateral radiographs are made. If no subluxation is seen on radiographs, the patient is discharged with the arm in the splint or a sling. The patient should be reevaluated in five to seven days. If the elbow subluxates or dislocates in extension or is noncongruent on the radiographs made at the follow-up visit, the forearm should be pronated and the stability of the elbow should be reassessed. If stability is restored, a hinged brace or cast-brace is applied with the forearm in full pronation. An extension block of 30 degrees is sometimes necessary. If the elbow requires an extension block of more than 30 to 45 degrees, surgical repair should be considered. Extension blocks should be gradually eased so that by three weeks the brace allows full motion. At each follow-up examination, the elbow should be reevaluated in exactly the same manner.

Instability may need to be assessed with the patient under general anesthesia, as this is sometimes the only way to adequately examine the joint for stability. This examination is easiest to perform and the findings are easiest to interpret with the arm in the overhead position. The arm then resembles a leg, and the elbow resembles a knee. To most surgeons, this is extremely helpful. The elbow is examined for valgus, varus, and posterolateral rotatory instability. Valgus stress-testing is performed with the forearm fully pronated so that posterolateral rotatory instability is not mistaken for valgus instability[13]. This happens because the ulna and the radius rotate as a unit away from the humerus in response to valgus stress when the lateral collateral ligament is disrupted. Forced pronation prevents posterolateral rotatory instability because the intact medial soft tissues are used as a hinge or fulcrum, just as the periosteum is used for this purpose during the reduction of a supracondylar fracture in a child. Varus stress-testing is easiest to perform with the shoulder fully internally rotated. Both valgus and varus stress-testing are performed with the elbow in full extension and then in about 30 degrees of flexion. Flexion unlocks the olecranon from the olecranon fossa. Posterolateral rotatory instability is diagnosed with use of the lateral pivot-shift maneuver of the elbow. If there is severe soft-tissue disruption, this test can have a false-negative result. With severe soft-tissue disruption, the elbow can sometimes remain dislocated even when it is flexed past 90 degrees. If suspected, this problem can be avoided by the examiner using his or her thumb to prevent the elbow from fully dislocating (or limiting the degree of subluxation during the pivot-shift test).

### *Lateral Pivot-Shift Maneuver*

Currently, the most common method of performing this test is with the patient placed supine on the examining table with the affected extremity overhead[65] (Fig. 3). The elbow is supinated, and a mild-to-moderate forced valgus stress is applied while the elbow is flexed past approximately 40 degrees. This maneuver results in apprehension or frank subluxation of the radius and the ulna in a rotatory fashion from the humerus. A visible, palpable clunk or an actual pivot shift may be elicited by this maneuver. If instability is not elicited, the test is still positive if there is apprehension, and the diagnosis can be made on this basis. The posterolateral rotatory drawer test involves placing the elbow in approximately 40 degrees of flexion and applying an anterior-posterior force on the ulna and the radius to subluxate the forearm away from the humerus on the lateral side (pivoting on the intact medial ligaments).

Stress radiographs are made in the anteroposterior plane with application of valgus and varus stress and the arm overhead as described above. With the shoulder in 90 degrees of abduction and full external rotation, stress radiographs are also made with the arm in supination and pronation to detect posterolateral rotatory instability and to determine if the medial side opens up with pronation (indicating disruption of the medial soft tissues).

### *Evaluation and Management of Acute Fracture-Dislocations*

The evaluation of a patient who has sustained a fracture-dislocation is very structured, and it is essential. Stress radiographs should be made, with use of an image intensifier, in the anteroposterior plane with valgus stress and then with varus stress. When valgus stress-testing is performed, the forearm must be held fully pronated with moderated force to prevent posterolateral rotatory subluxation and false-positive valgus instability. With the shoulder in 90 degrees of abduction and full external rotation, lateral stress radiographs are also made with the forearm in supination and pronation to detect posterolateral rotatory instability and to determine if the medial side opens up with pronation (indicating disruption of the medial soft tissues).

## The Terrible-Triad Injury

The elbow is one of the most stable articulations in the skeletal system, and when one or more parts of its articular supporting architecture is disrupted in the presence of a dislocation the risk of recurrent instability or arthrosis is substantial[7-9]. The fundamental goal in the management of fracture-dislocation of the elbow (a so-called complex dislocation) is the restoration of the osseous-articular restraints, thereby converting the injury to a so-called simple dislocation, which has been demonstrated in a number of studies to have a generally favorable long-term prognosis[8-9]. Most of the principles of managing complex instability of the elbow can be derived from an understanding of the pathomechanics and treatment of the terrible-triad injury. One of us (R. N. H.) used the phrase terrible triad for the combination of an elbow dislocation and fractures of the radial head and coronoid process[10]. It received this name because of the major disability that so often results from this injury[10]. The terrible triad often affects young active individuals, and the complications include persistent instability, nonunion, malunion, and osseous proximal radioulnar synostosis. In approaching the management of the terrible-triad injury, one must consider the individual injuries to the coronoid process, radial head, and collateral ligaments.

*Fractures of the Coronoid Process*

Regan and Morrey classified fractures of the coronoid process into three types[11]. Type I is a small fleck of bone, type II involves 50 percent of the height of the coronoid process or less, and type III involves more than 50 percent of the height of the coronoid process. Type-I fractures have been incorrectly referred to as avulsion fractures, but Cage et al. showed, in a cadaver study, that they are not, as nothing attaches to the tip of the coronoid process[12]. They represent shear fractures, similar to a Bankart lesion of the shoulder, and they occur during subluxation or dislocation of the elbow[13]. Regan and Morrey found that the prevalence of instability rises, and the prognosis deteriorates, according to the amount of the coronoid process that is fractured[11].

When the coronoid process is fractured, with or without concomitant fracture of the olecranon, restoration of the intrinsic stability of the elbow depends to a large degree on reestablishment of the anatomical dimensions of the trochlear notch. Fracture of the coronoid process at its base compromises stability in two ways. First, the anterior buttress, which serves to resist the normal posteriorly directed forces occurring with elbow flexion, and second, the anterior band of the medial collateral ligament, the insertion of which is attached to the coronoid fracture fragment, are rendered incompetent[11,12,14-17].

Beredjiklian et al., in a biomechanical study performed on cadavera, confirmed the role of the coronoid process as a primary stabilizer of the elbow and its critical role in the presence of a radial head fracture and ligament injury[18]. Two of us (S. W. O'D. and B. F. M.) and colleagues demonstrated, in a cadaveric model simulating the terrible-triad injury, that the coronoid process is a primary stabilizer of the elbow[19]. Persistent instability was progressively more likely as the amount of coronoid resection increased, even with the radial head present. However, with even a small deficiency in the coronoid process, the radial head became a critically important secondary stabilizer.

The operative exposures of the coronoid process depend on the associated lesions. A universal posterior skin incision, just lateral to the tip of the olecranon, permits deep access to both the medial and the lateral side of the elbow and provides the versatility needed to treat these injuries. In general, small (type-I and many type-II) fractures found in association with radial head fractures and dislocated elbows can be approached from the lateral side, as described by one of us (R. N. H.)[20]. An exception is a medial coronoid fragment (often part of a comminuted type-II or III coronoid fracture), which is more appropriately approached medially. The fractured radial head is retracted gently to permit access to the coronoid process. The medial approach is facilitated when the injury includes avulsion of the origin of the flexor-pronator muscle mass. Elevation of the ulnar origin of the flexor-pronator muscle group allows visualization of the coronoid process. When it is part of a complex proximal ulnar fracture, the coronoid process can occasionally be reduced, and the reduction can be held, by exposure through the olecranon fracture itself[21].

Internal fixation of smaller (type-I or II) fragments may present not only technical problems but also problems that may jeopardize the tenuous blood supply to the coronoid process. We prefer to use the technique of one of us (S. W. O'D.), in which two braided sutures are passed over the top of the small coronoid fragment, pulled out through drill-holes in the ulna, and tied over the bone[22] (Fig. 4). If the capsule is attached to the fragment, the sutures should be passed through the capsule

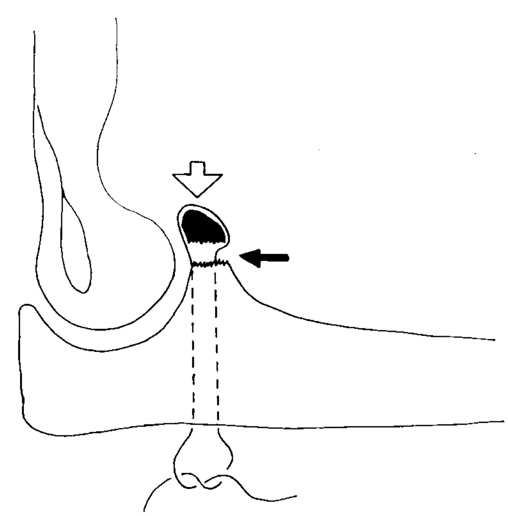

FIG. 4

Illustration showing internal fixation of smaller coronoid fragments (type I or II) with two braided sutures that are passed through the ulna and over the top of the small coronoid fragment and then tied over the bone[22]. If the capsule is attached to the fragment, the sutures should be passed through the capsule as well.

as well. Reattachment of a fractured coronoid fragment provides important stability through the capsular attachments, just as a volar plate advancement arthroplasty does for an unstable fracture-dislocation of the proximal interphalangeal joint.

Larger (type-III and some type-II) fractures of the coronoid process require anatomical reduction and stable internal fixation. The best techniques are not yet known, as experience with treating these injuries is limited. However, it is likely that screw fixation and the use of a buttress plate are necessary for most such fractures. This is particularly true for medial coronoid fractures.

In some instances, the coronoid may not be amenable to fixation because of the size or comminution of the fracture or because of a delay between the injury and the treatment. When the coronoid fracture is associated with a complex fracture of the radial head, a portion of the radial head can be shaped and secured with one or two interfragmentary screws. Alternative sources of osteochondral bone include tricortical iliac-crest bone graft, an allograft coronoid, and the proximal tip of the olecranon. If iliac-crest bone graft is used, the capsule should be interposed between the graft and the trochlea to prevent direct contact and cartilage erosion.

### *Results and Complications*

To our knowledge, the results of treatment of the terrible-triad injury have not been reported in a single series, but anecdotal experience justifies the name. In a series, reviewed by one of us (J. B. J.), of fifty-six patients who had a fracture-dislocation that was treated in Boston, thirteen patients had a posterior dislocation of the elbow associated with a fracture of the radial head and coronoid process. Ten of the thirteen elbows remained unstable following operative treatment, with early arthrosis seen in all, and only four of the thirteen patients had a satisfactory outcome. All but one had a type-II coronoid fracture, and one had a type-III fracture. It is of note that none of the type-II lesions had stable internal fixation. It is also noteworthy that 90 percent of the patients who had removal of the fractured radial head had an unsatisfactory outcome, whereas only one-third of the patients in whom the radial head was fixed had an unsatisfactory result.

This data supports the concept that the terrible triad is a grave and complex injury and suggests that lesions of both the coronoid process and the radial head need to be stabilized or reconstructed whenever possible.

## Fractures of the Radial Head

Fractures of the radial head are commonly associated with dislocation of the elbow and with isolated disruption of the medial collateral ligament, lateral collateral ligament, or interosseous membrane, or all three[23-25]. Fractures of the coronoid process, olecranon, and capitellum are also frequently associated with radial head fractures and may further impair elbow stability[26,27]. The presence of these concomitant injuries has important implications with regard to the management of a radial head fracture.

### *Anatomy and Biomechanics*

The radial head has a concave dish that articulates with the capitellum. The posteromedial two-thirds of the radial head articulates with the lesser sigmoid notch of the ulna, whereas the anterolateral one-third of the radial head has no articulation. Therefore, internal fixation devices can be placed anterolaterally on the radial head without impingement against the ulna during rotation of the forearm[28].

The radiocapitellar articulation accounts for as much as 60 percent of the load transfer across the elbow, and resisted isometric flexion can generate forces up to four times body weight[29,30]. Depressed fractures of the radial head decrease the surface area available for load transfer and decrease elbow stability by virtue of a loss of congruity of the articulating disc of the radial head with the capitellum. The radial head is an important valgus stabilizer of the elbow, particularly in the setting of an incompetent medial collateral ligament, which typically is disrupted in most fracture-dislocations[2,23,25,26,31-38].

### *Classification*

Mason classified radial head fractures into three types[39]. Type I indicates an undisplaced fracture; type II, a fracture with displaced wedge fragments; and type III, a comminuted fracture. Johnson added a fourth type, a radial head fracture associated with an elbow dislocation[40]. More recently, one of us (R. N. H.) developed a management-based classification system[20]. Type-I indicates a fracture that is undisplaced or minimally displaced (less than two millimeters); type II, a fracture that is displaced but amenable to internal fixation; and type III, a fracture that is not amenable to internal fixation with use of current techniques. The latter classification is preferable because of its implications with regard to treatment.

### *Imaging*

Anteroposterior, lateral, and oblique radiographs of the elbow usually provide sufficient information for the diagnosis and treatment of radial head fractures. Tomography or computerized tomography can be useful for evaluating selected fractures that are difficult to classify and can be helpful for preoperative planning. Posteroanterior radiographs of both wrists should be made for patients who have associated wrist pain and for those who have a comminuted fracture of the radial head because such patients have been found to have a higher prevalence of interosseous ligament injury[23].

### *Treatment*

A concomitant dislocation of the elbow should be reduced, and the radial head fracture should then be

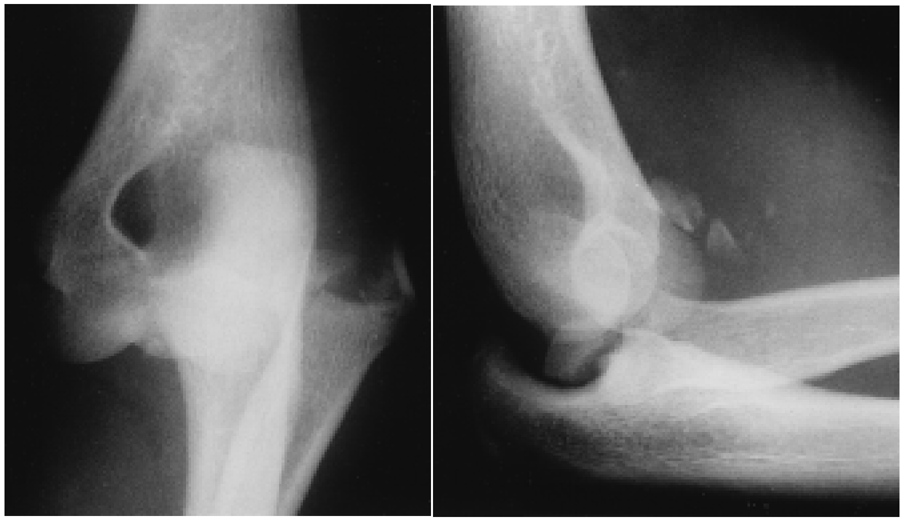

FIG. 5-A FIG. 5-B

Figs. 5-A through 5-D: A twenty-four-year-old man who fell off a mountain bike.

Figs. 5-A and 5-B: Anteroposterior and lateral radiographs showing dislocation of the elbow with a type-II radial head fracture, according to the classification system of Hotchkiss[20], and a type-II coronoid fracture, according to the system of Regan and Morrey[11].

managed on its own merits. Decision-making is influenced by patient-related factors (age, bone quality, and activity level) and fracture-related factors (fracture size, displacement, and location). For example, an older patient with osteoporosis and a comminuted radial head fracture is a poor candidate for internal fixation, with radial head arthroplasty being the preferred option in the setting of an associated elbow dislocation.

Undisplaced or minimally displaced radial head fractures (Hotchkiss type I) are occasionally seen with elbow dislocations, but displaced radial head fractures are more common when the elbow has been dislocated. As already mentioned, elbow dislocations with a radial head fracture also are typically associated with a coronoid fracture. When the elbow is dislocated and more than one-third of the radial head is fractured and displaced greater than two millimeters (Hotchkiss type II), open reduction and internal fixation of the radial head fracture should be attempted when it is technically possible[20,41-43] (Figs. 5-A through 5-D).

The management of displaced radial head fractures that are not amenable to internal fixation with use of current techniques (Hotchkiss type III) is controversial. Fragment excision, delayed excision of the radial head, and replacement of the radial head have all been considered. Acute excision of the radial head without re-

FIG. 5-C FIG. 5-D

Anteroposterior and lateral radiographs demonstrating an anatomical reduction after open reduction and internal fixation of the radial head and repair of the coronoid process with sutures. Early postoperative elbow motion was permitted, and a good result was achieved.

placement is contraindicated when there is concomitant disruption of the medial collateral ligament or the interosseous membrane[25,32,33]. Displaced fractures that block the rotation of the forearm and are too small, comminuted, or osteoporotic for stable internal fixation should be managed with fragment excision. The two prerequisites for fragment excision are evidence that the fragments to be excised do not articulate with the lesser sigmoid notch of the ulna and involvement of less than one-third of the radial head. Delayed excision of the radial head can be used for an isolated, comminuted, displaced fracture that involves more than one-third of the radial head and does not block forearm rotation, but it is not an option in a patient who has had a fracture-dislocation[44-46]. Arthroplasty of the radial head is indicated for displaced, comminuted radial head fractures when stable internal fixation is not possible and the fracture involves more than one-third of the radial head[47-54].

*Operative Techniques*

The patient is placed in the supine position on the operating table with a tourniquet in place. Prophylactic antibiotic therapy is administered, and general or regional anesthesia is initiated. As in the case of a coronoid fracture, a posterior elbow incision is used. This approach decreases the risk of a cutaneous nerve injury compared with that associated with a separate medial incision[55,56]. Disruption of the lateral collateral ligament complex and the common extensor muscles from the lateral epicondyle is commonly noted in patients with an elbow dislocation. This approach also simplifies the surgical exposure of the radial head[2]. The interval between the anconeus and the extensor carpi ulnaris (the Kocher interval) is identified and developed. The lateral collateral ligament is incised at the midportion of the radial head, with the surgeon staying anterior to the lateral ulnar collateral ligament[46,57]. The annular ligament often must be divided to improve exposure.

Internal fixation is performed with use of 1.5, 2.0, or 2.7-millimeter screws and plates or 3.0-millimeter cannulated screws, depending on the size of the fragment. If plate fixation is used, the plate should be placed on the nonarticular portion of the radial head, which is the lateral part of the radial head when the arm is in neutral rotation[58]. Screws should be countersunk to avoid impingement with the lesser sigmoid notch. Threaded Kirschner wires may be useful for small fragments not amenable to screw fixation. Smooth Kirschner wires should be avoided due to their tendency to migrate during the postoperative period.

A radial head with a fracture that is not amenable to fixation should be replaced with a metallic radial head when there is a medial collateral or interosseous ligament injury[25,32,33,47]. Silicone implants have been employed in the past; however, they have a high rate of failure due to fracture and fragmentation[25,32,33,47,54]. The fragmentation of silicone often produces synovitis. Clinical series of patients managed with metallic implants have shown good results[49,50]. Most metallic radial head implants have a monoblock design that makes implantation difficult because a wide surgical exposure is necessary. Recently, modular metallic radial head prostheses have become available. These prostheses have wider sizing options, and they may be easier to implant. A word of caution: the coronoid fragment should not be removed when the radial head is excised.

Following fragment excision, open reduction and internal fixation, or radial head replacement, the lateral collateral ligament complex and the common extensor muscle origins should be carefully repaired back to the lateral epicondyle with use of heavy sutures through drill-holes or suture anchors[57]. The fascial interval between the anconeus and the extensor carpi radialis also should be closed to augment lateral stability of the elbow[59]. The elbow should be carefully evaluated for stability, and concomitant injuries (for example, those involving the medial collateral ligament or the coronoid process) should be repaired when appropriate.

*Postoperative Management*

Indomethacin (seventy-five milligrams daily) has been recommended for patients with complex elbow dislocations, to control postoperative pain and to potentially reduce the prevalence of heterotopic ossification[58,60,61]. This medication should be avoided by patients with a history of peptic ulcer disease or a known allergy. An early range of motion within a safe arc should be initiated, depending on associated fractures and ligamentous injuries. An extension-splinting program[62] is initiated as soon as stability improves, and the splint is worn at night for twelve weeks.

*Complications*

Avascular necrosis might be expected following open reduction and internal fixation of most radial head fractures, as the fragments typically have a precarious blood supply or no blood supply. Fortunately, the fragments usually heal and late collapse is uncommon. Nonunion is usually associated with avascular necrosis and seems to be more common in patients with a fracture involving the radial neck. Malunion is usually a consequence of inadequate fracture fixation or collapse due to avascular necrosis. Osteoarthritis is seen as a consequence of articular cartilage injury from the initial dislocation, late instability, or articular incongruity. Stiffness is a common sequela of a radial head fracture and may be due to capsular contracture or heterotopic ossification. Late axial or valgus instability is uncommon unless the radial head has been excised.

## Hinged External Fixation for Unstable Elbows

It is not possible (or wise) to restore stability surgically after all dislocations or fracture-dislocations. In other cases, the constraints may have been repaired, but not securely, and need protection.

*Indications*

As with most surgical devices and methods, the two most important factors of success are how and when to apply them. This is especially true of hinged fixators about the elbow because of the difficulty and the time that application of the device adds to the procedure and to postoperative care. However, failure to use the device when indicated may result in a stiff and dislocated elbow, the worst of all worlds for a patient with a traumatized elbow.

The three primary indications are: (1) persistent instability in association with an acute fracture-dislocation despite attempted ligament repair and fracture fixation or radial head replacement, or both; (2) gross acute instability in a patient who is not a candidate for surgery; and (3) delayed treatment (approximately four weeks or more after the time of injury) of a dislocated and stiff elbow. A relative indication is the need to protect the stability and the fracture reduction during rehabilitation following surgical treatment of an unstable elbow.

The severity of a dislocation is seldom assessed, but it should be evaluated when hinged fixation is considered for the treatment of instability. Gross instability is not a condition that is easily recognized, but there are a few distinguishing features. In most cases, the patient has one or more of the following features: (1) a high-energy injury — that is, an injury sustained in a fall from a considerable height or in a motor-vehicle accident; (2) previous failed attempts at reduction or surgical repair of the dislocation; (3) multidirectional instability on examination after attempted or achieved reduction; and (4) a concomitant fracture of the radial head or the coronoid process, or both (the terrible triad of the elbow). None of these features alone creates a grossly unstable elbow, but if any one is present the others should be looked for.

Hinged fixation is used most commonly as a secondary device to protect surgically repaired or healing structures while permitting and assisting proper kinematic motion. Even if they are not repaired, the medial ligaments usually heal with mechanical integrity if they are protected. Conversely, the lateral ligaments should be repaired or reconstructed, as detailed in other sections.

There are a few situations in which application of the devices alone may be both adequate and optimal. In patients who have polytrauma, time may not permit full anatomical restoration of all structures. In this setting, protecting the elbow in a reduced position before definitive care will assist in the subsequent treatment.

*Operative Technique*

At the current time, three very different hinged external fixators for the elbow are commercially available. They each have their own advantages and disadvantages. With two of the devices, the use of a temporary axis pin is crucial to replicate the kinematic axis of the elbow. In earlier reports and designs, the axis pin was left in place in the distal part of the humerus for the duration of use[62]. However, because pin-track infection at the site of the axis pin led to joint infections, a temporary axis pin is now used with all of the devices. The long-term use of a pin through the axis of rotation at the distal aspect of the humerus is no longer recommended.

In most cases, repair of the fractures and ligaments obviates the need for a fixator. To determine if a fixator is needed, the stability of the joint should be gently tested before application of the fixator, while the ligament sutures are held under tension. If the elbow is stable and the fractures require minimal protection, no fixator is needed.

When the hinged fixator is applied after fixation of the fractures, care must be taken not to disrupt the ligament repair and the delicate fracture fixation. Repair of the coronoid process, so crucial to long-term success yet often quite vulnerable to loading during application of the hinge, must be protected during placement of the device. It is often better to position the sutures for ligament repair without securing them with knots, in anticipation of fixator placement. Because of unfamiliarity with the device or the complexity of fixator application, the repaired ligaments and fractures could be subjected to failure loads, defeating the purpose of the repair efforts. If the sutures for ligament repairs are tied in place after the fixator is applied, tension in the repairs is achieved with confidence that there is no eccentric displacement of the repair.

*Technical Tips*

The proper technical application of these devices cannot be overemphasized. The most crucial and usually the first step of hinged fixator application is replication of the recognized axis of rotation. If the axis is not replicated or if pin placement in the humerus or ulna impedes motion, the use of the device is entirely compromised and provides little, if any, value. Since the axis of elbow motion is within the distal aspect of the humerus, the frame is attached to the humerus first. A temporary joint-axis pin is placed, and the frame is built from this temporary axis pin. Once the fixator is properly attached to the humerus, the ulna may be reduced and attached to the fixator.

In most cases in which an operation is performed on a grossly unstable elbow, both the medial and the lateral aspect of the distal part of the humerus are exposed and visible. This permits visualization of the instant center of rotation on both sides. The temporary axis pin should penetrate both central points of rotation, ensuring proper function of the hinge. If the distal part of the humerus is not directly visible, the pin and axis must be visualized with fluoroscopic imaging. There are many methods for placement of the axis pin across the distal aspect of the humerus, and these are usually detailed in the instructional materials provided for each particular device. Anterior-cruciate-ligament drill-guides or variations of them may help.

On the medial side, injury to the ulnar nerve is avoided by exposing the nerve anchor or transposing it, or both. The center of rotation from the medial view is slightly distal and anterior to the medial epicondyle. From the lateral view, the center of rotation is in the center of the capitellum. If there is concern about the location on visual inspection, fluoroscopic images should be made. Both the anteroposterior and lateral views are needed to properly ascertain the pin location. As one gains experience, the localization and placement becomes less time-consuming and challenging.

After the axis pin is properly placed in the distal part of the humerus, pin fixation of the frame to the humerus must be done. Adjustment of pin fixation may be necessary if plates on the distal part of the humerus or the proximal part of the ulna interfere with the normal pin position.

Secure fixation of the frame to the distal part of the humerus may require more than just two pins (one medial and one lateral) in the supracondylar region of the humerus. In such cases, an extension can be added onto the frame, with half-pins placed in the humerus more proximally. When pins are placed more proximally in the humerus, the radial nerve should be protected from injury. The half-pins should also be placed to avoid impaling muscle or tendon, as this will impede movement. Placement of pins in the ulna is usually simpler.

Half-pins attached to the fixator should be placed so that there is no skin under tension. The skin tension against the pins should be inspected in all positions of flexion and extension. Skin under tension should be released. Redness, pain, and drainage are avoided by meticulous pin-site care. If skin tension is noted later, it should be released. Antibiotics may be needed if there is erythema and increased pain.

Loss of reduction and mechanical failure can occur. Frequent clinical examination and radiographs to confirm maintenance of the reduction are mandatory. The clamps, nuts, bolts, and frames should be inspected frequently for any loosening during the first few weeks. As rehabilitation activity becomes more vigorous, there is also more stress on the components, which can lead to loosening of the pins in the bone or component failure, or both. The components should be routinely inspected for signs of fatigue.

## Recurrent Elbow Instability

Lateral collateral ligament insufficiency is most commonly seen after elbow dislocation, particularly in young patients. It is the essential lesion leading to elbow instability[36]. While most studies have indicated that both the medial and the lateral collateral ligament complex are acutely disrupted with an elbow dislocation, the residual insufficiency most commonly involves the lateral collateral ligament complex for reasons that have not yet been elucidated. This insufficiency gives rise to recurrent posterolateral rotatory instability[37].

### *History*

In the vast majority of patients, dislocation with or without fracture accounts for the injury[63]. Sometimes the problem is quite obvious, as the patient is able to demonstrate the instability; however, it may be more subtle. Sometimes the patient has noticed only pain and discomfort and is not aware of instability. Additional symptoms include painful catching, slippage, or clicking with flexion and extension. A feeling of slippage of the joint in and out of place may be reported by the patient. The elbow position most typically associated with symptoms is approximately 40 degrees of flexion with the

FIG. 6

Lateral radiograph of an elbow with recurrent posterolateral rotatory instability, showing the radial head to be aligned posterior to the capitellum. The ulnohumeral relationship does not appear to be grossly abnormal but, in fact, reveals subtle subluxation.

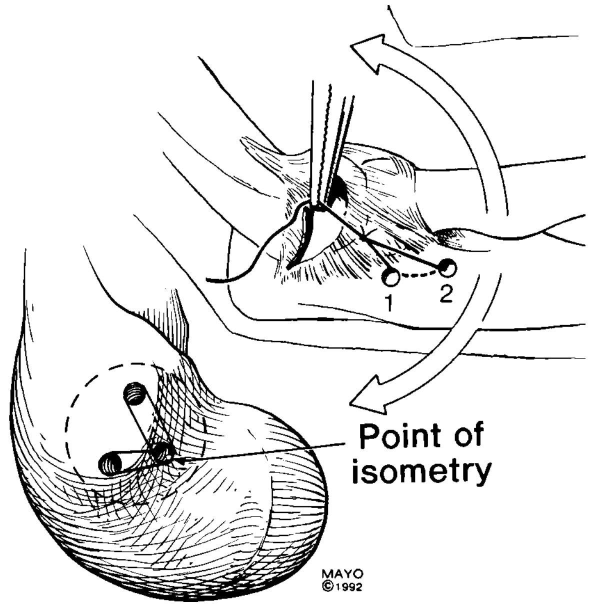


FIG. 7-A

Drawing showing a suture being passed through the osseous tunnels in the ulna distal to the tubercle of the supinator crest. The isometric point is determined by the point at which there is no laxity or increased tension on the suture through the arc of elbow flexion.

forearm in supination. The subluxation reduces in pronation. The patient may have noted that specific activity such as pushing on the armrests when rising from a chair reproduces the symptoms of instability.

The physical examination includes the lateral pivot-shift maneuver, the posterolateral rotatory drawer test, and the apprehension test. In some instances, varus stress-testing may suggest a lateral collateral ligament insufficiency. Rising from a chair while pushing on the armrests has been suggested by Morrey and Regan to be particularly helpful, either to demonstrate the instability or as an apprehension-eliciting maneuver[64].

*Radiographs*

Classically, the elbow appears normal on anteroposterior radiographs or there is slight widening of the radiohumeral joint. On lateral radiographs, the radial head may appear to be situated posterior to the capitellum (Fig. 6). Special studies, magnetic resonance imaging, and computed tomography have not been necessary or useful in our experience.

*Arthroscopy*

In some instances, when the presentation does not suggest the injury or the findings on the physical examination are not convincing, or when there is a possiblity of an intra-articular lesion, arthroscopic examination of the elbow may be helpful. Arthroscopy will reveal the laxity of the radiohumeral joint and thus confirm the lesion.

*Management*

In our experience, the ligament does not become stable over time, except possibly when a patient is seen in the very early stages. By definition, this is a recurrent problem, and it needs a surgical reconstruction or the patient must live with the problem. The latter is rarely acceptable to the patient, as symptoms interfere with daily activity.

*Surgical Technique*

The patient is placed supine on the operating table, and the arm is brought across the chest. A ten-centimeter incision is made at the Kocher interval, roughly equidis-

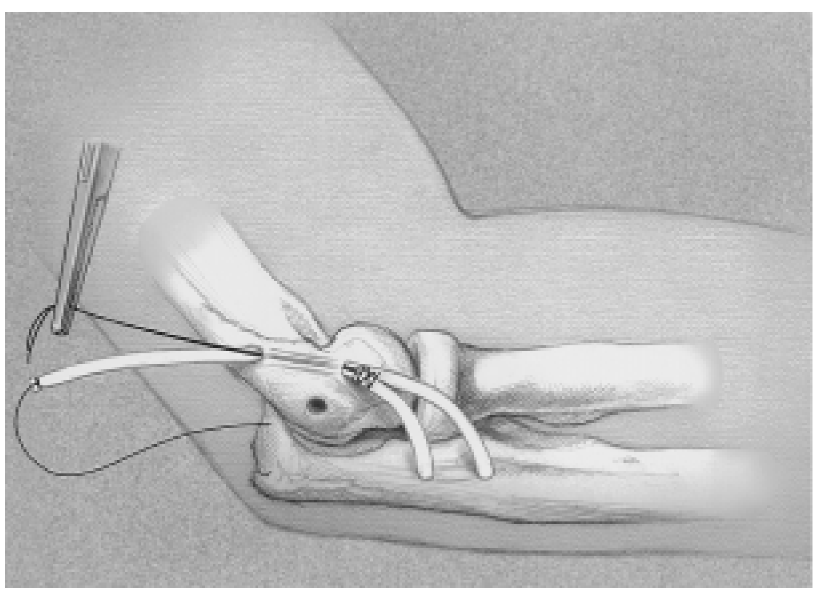

FIG. 7-B

Illustration showing a tendon (palmaris longus) graft placed through holes in the ulna and brought into the isometric origin near the lateral epicondyle, out through an exit tunnel proximally, and back into the bone for fixation.

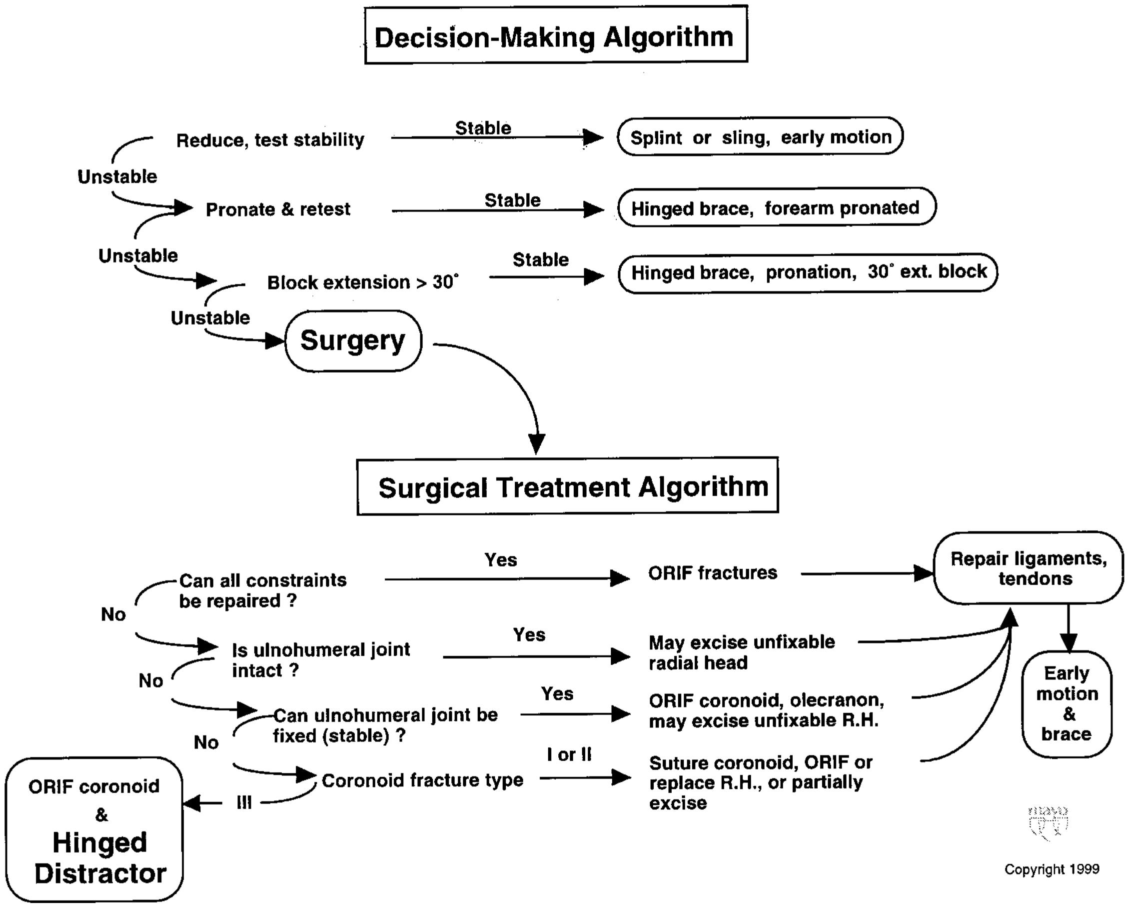


FIG. 8

Chart showing the decision-making algorithm for acute dislocations and fracture-dislocations. The term stable implies functional stability, meaning that the elbow does not apparently subluxate in the functional arc of motion and appears reduced on plain radiographs. ORIF = open reduction and internal fixation, and R.H. = radial head.

tant proximal and distal to the epicondyle. The dissection proceeds through the Kocher interval, with separation of the anconeus from the extensor carpi ulnaris and identification of the lateral collateral ligament complex, the supracondylar ridge, and the crest of the supinator. The anconeus is further reflected from the margin of the supinator crest and from the lateral face of the proximal part of the ulna. The tubercle of the supinator ridge is palpated. The lateral epicondyle is exposed along with two centimeters of the proximal supracondylar ridge anteriorly and posteriorly.

The insertion site for the tendon graft is then prepared by creating two drill-holes in the ulna: one, near the tubercle on the supinator crest (which is felt by stressing the elbow in varus or supination) and the other, 1.25 centimeters proximally at the base of the annular ligament (Fig. 7-A). A suture is passed through these two holes and tied to itself. It is then pulled toward the lateral epicondyle and grasped with a hemostat at the estimated isometric center of the rotation of the elbow. The isometric ligament origin is then determined by flexion and extension of the elbow to see if the suture moves. No movement occurs when the suture and hemostat are on the isometric point. The isometric point is more anterior than is usually thought to be the case. It is important to remember that instability occurs in extension so the graft must be taut in extension. A Y-shaped tunnel is placed in the lateral epicondyle, with the isometric spot widened in order to accept a three-ply graft. Currently, one of us (B. F. M.) prefers to use the plantaris tendon if a substantial palmaris longus is not present. A sixteen-centimeter graft allows a reliable three-ply passage across the joint (Fig. 7-B). There are a number of options for fixing the graft into the humerus. One or both limbs of the graft pass into the isometric origin. We prefer to place a stitch in the first two limbs of the graft after the graft is passed through the tunnel in the ulna. Both this stitch (the yoke stitch) and the graft are then passed through one of the tunnels in the humerus. The free end of the graft just reaches the tunnel, ensuring a two-ply passage as the free end of the tendon graft is brought through the holes in the epicondylar region and back down distally across the joint. This end is usually passed back into the ulnar tunnel if sufficient length is present. If not, it is sutured to itself distally near the ulnar tunnel. Once this has been done, the forearm is placed in 40 degrees of flexion and full pronation while axial tension is placed on the yoke stitch, which is then tied. This applies additional tension to the reconstruction.

*Rehabilitation*

The elbow is placed in 70 to 80 degrees of flexion with the forearm in full pronation. The arm is held in this position for ten to fourteen days, and then the patient is permitted protected motion in a hinged brace for two to six weeks, with flexion allowed as tolerated. After six weeks, the patient may remove the hinged splint for sedentary activities, but otherwise the splint is worn for most activities. At the end of an additional six weeks, the use of the splint is discontinued, but conscious protection is recommended for a total of twelve weeks after surgery. Supination is gradually allowed and encouraged, but excessive force is avoided. After twelve weeks, activity is gradually resumed, with 100 percent activity allowed at six months.

*Results*

Although we are currently reassessing our clinical experience, to date it has been suggested that, if there is no degenerative arthritis and if the radial head is intact, approximately 90 percent of patients have a satisfactory outcome with no subsequent recurrent subluxation[66]. If the radial head is excised or if there is degenerative arthritis of the ulnohumeral joint, the satisfactory result decreases to between 67 and 75 percent. Delayed laxity, redislocation, and reinjury have been observed, usually in association with substantial stress. We accept a mild (10-degree) flexion contracture, since the most vulnerable position of instability is in full extension.

## **Summary of Treatment Principles** (Fig. 8)

*Reduction of Acute Dislocations and Management After Reduction*

The initial treatment of an elbow dislocation without associated fractures is a closed reduction. The reduction should be done with the forearm in supination to clear the coronoid process under the trochlea, thereby minimizing additional trauma to the medial soft tissues that have not yet been disrupted. Essentially, the deformity is recreated in order to make the reduction possible and easy. A simple principle to follow in managing a patient after reduction is to place the elbow in a splint for a brief period (three to five days) and then to start allowing movement unless the elbow tends to subluxate or dislocate. One must be vigilant. Subluxation or dislocation must be detected by careful examination throughout the comfortable range of motion and by radiographic examination, with anteroposterior and lateral radiographs made initially after the reduction and every five to seven days for the first three weeks. If subluxation or dislocation is detected clinically or radiographically at any time, a change of treatment is required.

The so-called stage or degree of instability dictates the treatment. If the elbow feels stable in all positions of forearm rotation, a hinged brace is not necessary. Such stability is usual. When the elbow is stable to valgus stress only with the forearm in pronation (that is, a stage-3A dislocation), the injury is treated immediately in a cast-brace that allows unlimited flexion and extension and holds the forearm in full pronation.

*Management of Acute Fracture-Dislocations*

The presence of fractures usually changes the management, and almost always these fractures should be treated surgically. In general, the approach to the unstable elbow is to fix the bones internally and then repair the ligaments (particularly on the lateral side) so that early motion can be commenced.

The coronoid process is an important part of the force-bearing surface of the elbow and is important for stability. Type-I and type-II fractures (those involving 50 percent of the height of the coronoid process or less) should be fixed if the joint is subluxated or dislocated. Type-III fractures (those involving more than 50 percent of the coronoid process) cause instability and should be fixed. Type-III fracture-dislocations have traditionally been associated with a poor prognosis.

Fractures of the radial head associated with an elbow dislocation or subluxation are best managed by internal fixation when technically possible. When the radial head is comminuted and has to be excised, prosthetic replacement is indicated if the elbow is unstable and cannot be rendered stable by ligament reconstruction alone.

*Repair of an Acute Ligament Injury*

Repair of an acute ligament injury is indicated in all fracture-dislocations requiring internal fixation of the radial head or the coronoid process, or both, and following reduction of a dislocation if gross instability does not allow early protected motion in a cast-brace without subluxation. In such cases, the ligament or ligaments may have been avulsed and can be repaired directly to bone with heavy sutures. In some cases, passing a heavy absorbable suture through the same course as that for a late ligament reconstruction and fixing it to the normal ligament attachments on the epicondyle and the ulna augments the repair.

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