CHAPTER 2

Posttraumatic Elbow Stiffness: A Review of the Literature
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Abstract
Loss of motion is a common complication of elbow trauma. Restoration of joint motion in the posttraumatic stiff elbow can be a difficult, time-consuming, and costly challenge. In this review of the literature, the biologic response to trauma and the possible etiologic events that may lead to fibrosis of the capsules and heterotopic ossification will be discussed, as well as nonsurgical and surgical management of stiffness and expected outcomes of treatment.

Introduction
Stiffness of the elbow joint has long been recognized as a complication of elbow trauma. Hippocrates (400 BC) emphasized the importance of immediate reduction and recommended immobilization in 90° of flexion: “an arm ankylosed in the extended position would be better away for it would be of great hindrance and of little use to the patient.” Despite advances in the management of injuries about the elbow, loss of elbow motion remains a common result. Restoration of joint motion in the posttraumatic stiff elbow can be a difficult, time-consuming, and costly challenge. In this review of the literature, the biologic response to trauma, the possible etiologic events that may lead to fibrosis of the capsules and heterotopic ossification, nonsurgical and surgical management of stiffness, and expected outcomes of treatment will be discussed.

Etiology
Loss of motion of the elbow is commonplace after elbow trauma. The etiology of posttraumatic stiffness can be multifactorial and can include arthrosis, heterotopic bone, or failure of fracture healing along with contracture of the soft tissues around the elbow. Why the elbow is so prone to contracture has been open to debate and deserves further investigation. Regan and Reilly postulated 3 potential factors: (1) the complex articular congruity and conformity of the elbow, (2) the brachialis muscle that covers the anterior capsule, predisposing it to posttraumatic heterotopic ossification, and (3) the often prolonged immobilization due to the difficult challenge of achieving stable fixation of complex comminuted fractures.
Kay established a classification system of the stiff elbow based on the specific components involved. According to his classification, type 1 involved soft tissue contracture; type 2, soft tissue contracture with ossification; type 3, undisplaced articular fracture with soft tissue contracture; type 4, displaced intra-articular fracture with soft tissue contracture; and type 5, involved posttraumatic bony bars. Morrey classified stiffness on the basis of the anatomic location of the contracture: intrinsic factors (intra-articular changes), extrinsic factors (extra-articular changes), or a combination of the two. Intrinsic factors include intra-articular adhesions, articular malalignment, loss of articular cartilage, or a multifaceted cause, whereas
extrinsic factors encompass contracture of the soft tissues (eg, the joint capsule or collateral ligaments), heterotopic ossification, or extra-articular malunions. Because there is often more than 1 anatomic structure involved, it is useful to use this classification. Mixed involvement is most common (ie, extrinsic contractures will almost always have an intrinsic component). Most authors agree that prolonged immobilization can lead to capsular contracture and that early active mobilization after the initial injury will be a factor in limiting residual stiffness.

Although several reports in the literature have described the beneficial effects of manipulation therapy without exacerbation of heterotopic ossification, there remains some debate regarding the relationship of passive elbow mobilization and resultant heterotopic ossification. We recommend that forceful and repeated manipulation of the stiff elbow should be avoided as experimental models have shown the development of heterotopic ossification under these circumstances, yet gentle passive motion may be indicated postoperatively. In addition, multiple surgical interventions within the first weeks after trauma, thermal burns, and associated head trauma have been suggested to predispose for heterotopic ossification.

**Soft Tissue Contracture**

**Pathophysiology**

Contracture of the soft tissues around the elbow primarily concerns the capsule and the ligaments. Animal models have demonstrated elevated numbers of myofibroblasts that have highly contractile properties and increased proliferation of extracellular matrix in experimentally induced contracture of knee and elbow capsules. In addition, increased formation of collagen cross-links, together with decreased proteoglycan content and decreased water content, may be characteristics of abnormal tissues in experimentally induced joint contractures. All of the above may be related to the increased expression of transforming growth factor beta (TGF-β) that was found in contracted rabbit elbow capsules. These processes may result in scarring of the capsule by fibrosis with resultant contracture of the joint.

It has been suggested that mechanical stimulation of injured periarticular structures, such as may occur with efforts to gain or maintain motion, may contribute to tissue contracture by an alteration in collagen synthesis. The medial collateral ligament may be prone to scarring that results in stiffness because of the persistent stress it sustains as a consequence of the carrying angle of the elbow. The exact mechanism that leads to contracture of the soft tissues merits further investigation. Better understanding of the pathogenesis of the fibrotic elbow capsule will potentially lead to more effective nonsurgical management of posttraumatic stiff elbows in the future.
**Heterotopic Ossification**

**Pathophysiology**

Heterotopic ossification leading to loss of motion is uncommon after elbow trauma.\(^2^6\) When associated with identified risk factors such as concomitant head trauma, the incidence increases substantially.\(^3^0\) Heterotopic ossification is the inappropriate formation of mature lamellar bone in soft tissues, which differs from the commonly seen periarticular calcifications, in which amorphous calcium deposits form in soft tissues around the elbow after injury.\(^2^0,3^9\) The formation of heterotopic bone is caused by pluripotential mesenchymal stem cells that differentiate into osteoblasts (stimulated by, eg, trauma, surgery, or inflammation), which produce osteoid\(^4^0\) that mineralizes into bone.\(^4^1\) This requires osteogenic precursor cells, an inductive agent (most likely a growth factor), and an environment conducive to osteogenesis.\(^4^2\) The heterotopic bone that subsequently develops is histologically identical to native bone but is more metabolically active and does not have a true periosteal layer.\(^4^3\)

**Prevention**

Prevention of heterotopic ossification is based on 3 principles: (1) disrupting the signaling pathways, (2) altering the relevant progenitor cells in the target tissue, and (3) modifying the environment conducive to heterotopic osteogenesis.\(^4^2\) Anti-inflammatory drugs (for disruption of inductive signal), preoperative irradiation (for disruption of responsive cells), and postoperative etidronate (for disruption of conducive environment) may all have an inhibitive effect.\(^4^2\)

Nonsteroidal anti-inflammatory drugs (NSAIDs) inhibit the enzyme cyclooxygenase, which is needed for the production of prostaglandins. Lowering prostaglandin levels raises the threshold for heterotopic ossification,\(^4^4\) because the induction of heterotopic ossification is stimulated by prostaglandins together with bone morphogenetic proteins.\(^4^5\) The use of nonselective NSAIDs, such as indomethacin, ibuprofen, and naproxen, have all been related to reduced formation of heterotopic bone, in particular in the hip.\(^4^6-5^0\) Although frequently used,\(^8,2^1,5^1-5^3\) the role of NSAIDs in prevention of heterotopic ossification around the elbow is unclear, and a comparative trial is needed.\(^5^4\) The possible beneficial role of selective NSAIDs that inhibit cyclooxygenase 2 is uncertain because of the associated risk of serious cardiovascular side effects.\(^5^7\) Diphosphonates that interfere with the calcification of osteoid are also considered a poor choice, as rebound calcification is to be expected after discontinuation,\(^5^8\) and side effects include serious gastrointestinal complaints and osteomalacia.\(^5^9\) Gene therapy with BMP antagonists might offer some potential for future treatment, as a preventive effect on the formation of heterotopic bone has been shown in an experimental animal model.\(^6^0\)
An alternative prophylaxis is the use of low-dose irradiation within 72 hours after the trauma to alter the progenitor cells in the target tissue. Stem cells are particularly radiosensitive, and irradiation prevents them from differentiating into osteoblasts. A possible inhibiting effect on the formation of heterotopic bone has been described with doses ranging from 600 to 1,000 cGy. The prevalence of radiation-induced osteosarcoma is low in humans. In addition, in a retrospective review of medical records from a period of 50 years, radiation-induced bone sarcoma was not reported with doses of less than 3,000 cGy. High doses of sodium etidronate may inhibit the angiogenesis needed for the mineralization of bone matrix and thereby reduce ossification but are not recommended as they predispose to osteomalacia and impair the ossification of normal bone.

Malunions and Nonunions
Intra-articular and extra-articular malunions and nonunions of the distal humerus, proximal ulna, and radial head may cause pain, instability, and severe limitation of elbow function.

Extra-articular malunions of the distal humerus
The lateral column of the distal humerus is curved anteriorly with the lateral epicondyle translated anteriorly with respect to the humeral diaphysis, whereas the medial column and medial epicondyle are more in line with the diaphysis. The use of straight plates on the lateral column of the distal humerus may lead to loss of anterior translation of the articular surface of the distal humerus. This can result in a smaller axis of rotation that causes less space for the coronoid and muscles and soft tissues during elbow flexion. The use of precontoured plates on the lateral column may be helpful to restore the original anatomy of the distal humerus and thereby prevent malunion. Treatment of a distal humerus fracture in which there is metaphyseal comminution may lead to shortening in spite of bridging the comminution. This may cause loss of the fossae, which results in limited flexion and extension. In addition, implants, scar tissue, fracture callus, and heterotopic bone may obstruct the coronoid, radial, and olecranon fossae. In the treatment of elbow stiffness due to malunion of a distal humerus fracture, the fossae should be cleared of heterotopic bone, scar tissue, and implants with a burr used to deepen or enlarge the fossae, even to the point of creating a hole through the distal humerus using the Kashiwagi technique. An extra-articular osteotomy with subsequent bone grafting and internal fixation may be considered in the case of an unsuccessful capsular release and debridement of fossae.

Intra-articular malunions
Malunion of intra-articular distal humerus fractures is commonly associated with loss of motion. Malunited anterior shearing articular fractures may be treated with osteotomy and capsular release to restore motion. Uneven articular surfaces with subsequent
incongruency of the ulnotrochlear articulation can lead to stiffness and arthrosis. The preservation of appropriate contact between the medial trochlea and the anteromedial facet of the coronoid process and between the capitellum and the radial head is considered important in maintaining a mobile joint. Malunited fractures of the radial head typically present as forearm stiffness rather than ulnohumeral stiffness and radiocapitellar or radioulnar arthrosis and in most instances can be treated successfully by radial head resection.

Arthrosis and stiffness after intra-articular fractures of the proximal ulna can be related to both instability as well as joint incongruity. Adequate restoration of the normal anatomy of the ulnotrochlear notch and the coronoid process is important to prevent arthrosis and instability of the elbow. Lack of the coronoid as an anterior buttress can result in malalignment with subsequent anterior subluxation of the distal humerus. Inadequacy of the coronoid is difficult to treat. The use of an osteoarticular autograft or allograft may prove useful to restore the coronoid, particularly for small coronoid fractures that are part of a terrible triad injury.

Nonunions

Nonunion after intra-articular fractures of the distal humerus occurs usually at the supracondylar level rather than at the intra-articular level. Nonunited distal humeral fractures may lead to pain, instability, and stiffness, the latter in many patients caused by motion occurring at the nonunion site with ankylosis or near-ankylosis of the joint itself. A combination of debridement of the nonunion site, realignment and stable internal fixation, autogenous bone grafting, elbow capsulectomy, and an intensive postoperative rehabilitation program have been shown to result in improvements in union rate and elbow function. In the older patients with limited demands, a total elbow arthroplasty may be considered. Loss of motion is not common, and an eventual surgical intervention would consist of debridement, bone grafting, and internal fixation but may not be necessary in all patients. Nonunion may also be the result of a neglected or inadequately treated simple olecranon fracture or an ununited olecranon osteotomy. Fortunately, significant loss of motion is not common, and an eventual surgical intervention would consist of debridement, bone grafting, and internal fixation but may not be necessary in all patients. Recently, satisfactory results for treatment of olecranon nonunions during total elbow arthroplasty were reported.
Nonunions of nonsurgically treated (isolated) radial head fractures are uncommon\(^{99,100}\) and in general cause little or no pain and usually do not interfere with motion\(^{99}\), therefore surgical treatment of the nonunion may not be needed\(^ {98,99}\). Nonunions of surgically treated radial head fractures are usually caused by broken or loose implants and lead to restricted forearm rotation and pain.\(^{101,102}\) Removal of radial head and implants usually relieves pain and restores motion.\(^{101}\) In view of the fact that total elbow arthroplasty has the potential risk of loosening over time as well as requiring marked limitation of function, it has been indicated primarily for older patients whose major problem is a painful stiff elbow.\(^ {9,103,104}\)

**Assessment**

A functional arc needed to perform most basic daily activities is defined as an arc of flexion from 30° to 130° and an arc of forearm rotation from 50° of pronation to 50° of supination.\(^ {105}\) However, the functional impairment depends on the individual requirements of each patient.\(^ {106}\)

It is important to understand the original injury and initial treatment as well as other associated conditions such as neurologic dysfunction, infection, and ipsilateral limb injury.\(^ {106,107}\) In most cases, posttraumatic stiffness is not painful, especially at rest, and pain usually is not present during flexion and extension. Pain with motion suggests the presence of arthrosis and/or ulnar nerve dysfunction\(^ {106}\), whereas patients with pain at rest and a history of surgery are at risk for a low-grade infection; therefore, laboratory studies should include a C-reactive protein level and an erythrocyte sedimentation rate\(^ {107}\). The elbow should be aspirated prior to surgery if these values are abnormal and warmth or other evidence of inflammation is present. The ulnar nerve is commonly involved in elbow trauma and deserves special attention during the examination of the entire upper extremity.

Although anteroposterior and lateral radiographs are sufficient in most patients\(^ {107}\), assessment may be more complete with computed tomography (CT) scans\(^ {65}\) and even more with 3-dimensional CT scans, particularly when heterotopic bone is present\(^ {11,53,106,108}\) (Fig. 1). Although magnetic resonance imaging (MRI) defines the soft tissues around the elbow, it is not considered useful in the evaluation of elbow contracture because it does not define the heterotopic ossification and joint anatomy as well as CT imaging.\(^ {20}\)

Heterotopic ossification presents as local soft-tissue swelling, warmth and tenderness, easily mistaken for infection, cellulitis, thrombophlebitis, tumor, or soft tissue (nonosseous) calcification.\(^ {20,39,42}\) The end points of motion become rigid or abrupt instead of compliant as seen with some soft tissue contractures, and motion at the limits may be painful.\(^ {20}\) Pain through the central flexion arc suggests joint incongruity or degeneration of the ulnotrochlear
Figure 1. (A–C) Three-dimensional reconstruction of CT scans clearly depict the heterotopic bone around the elbow which may be helpful for operative planning. (Images courtesy of David Ring, MD, PhD.)

joints or the radiocapitellar joint in the case of pain through the central arc of forearm rotation. Heterotopic ossification can manifest from 2 to 12 weeks after the inciting event (trauma, surgery, burn, or neurologic insult). The maturity of the heterotopic bone as well as the time since onset is important for the timing of eventual surgical intervention. Technetium-99m bone scans are no longer used to evaluate bone metabolic activity, because they do not provide useful prognostic information. The progression of heterotopic ossification should be evaluated radiographically; a cloudy periarticular density may be seen within several weeks after injury and subsequent maturity is indicated by smooth, well-demarcated cortical margins and defined trabecular markings, generally about 3 to 6 months after its appearance. Although early excision of heterotopic bone was not recommended because this was thought to predispose to recurrence, most authors do now agree that surgical excision can safely proceed as soon as maturity is seen radiographically. Advantages of early resection include minimizing capsular and ligamentous contracture, muscle atrophy, and cartilage degeneration, and allowing a more rapid functional recovery. In skeletally immature individuals, nonbridging heterotopic bone may resorb over time, therefore it may be wise to wait longer in children.

The classification system of Hastings and Graham is useful for clinical assessment, treatment, and operative planning. Class I represents heterotopic ossification not causing functional limitation and is therefore clinically insignificant, although prophylactic treatment may be considered. Patients with class II heterotopic bone have a functional limitation of motion: class IIA represents ulnohumeral limitation less than a (100°) flexion arc from 30° to 130°, class IIB concerns limitation of forearm rotation less than a (100°) arc from 50° pronation to 50° supination, and class IIC concerns heterotopic bone causing limitation in both planes. Patients with class III heterotopic ossification have ankylosis that prevents either
ulnohumeral motion, forearm rotation, or both. It may be useful to subclassify class III according to the planes of limited motion: class IIIA no ulnohumeral motion, class IIIB no forearm rotation, and class IIIC no motion in either direction.20

Heterotopic bone was traditionally considered a complicating factor for surgical release and associated with poor outcomes, in particular in presence of a complete bony bridge.114-116 However, more recent studies have suggested that patients with nonbridging heterotopic ossification that complicates capsular contracture may regain even more motion after surgical release than patients with a capsular contracture alone.8,21

Nonsurgical Treatment

If posttraumatic stiffness develops in spite of precautionary measures such as early active motion, it has the potential for successful nonsurgical treatment. Regaining joint motion in the most time-efficient manner is critical for return to function, control of rehabilitation costs, and to prevent the need for additional surgery.

The use of turnbuckle-like splints to restore motion of the posttraumatic stiff elbow was described in the Medieval era by the German surgeon Hans von Gersdorff (1455–1529)3 (Fig. 2). Today, adjunctive splinting devices are still added to the traditional rehabilitation program and may help to prevent the need for surgical intervention. Splints are especially effective in patients with contractures of relatively short duration and little articular involvement.19 Satisfactory restoration of motion with use of static progressive turnbuckle splints (that apply a static stress relaxation force to the elbow tissues, which is sequentially increased as motion is achieved) has been described in several studies.117-121 Dynamic splints that apply a constant prolonged force to the tissues as additional motion is achieved are a popular alternative with satisfactory results reported.21,122-124

Surgical Treatment

If nonsurgical treatment fails to restore a functional arc of motion, surgical treatment may be considered.8,19,106,125,126 Traditionally, surgery has been offered to patients with flexion contractures or extension contractures of at least 30°. However, the justification of surgical intervention is highly individualized, and the patient’s needs and the ability of the surgeon to realize these expectations should be considered, with a mutual assessment of risks and benefits of the intervention.20,64,107 There should be radiographic union of the fractures, and the patient must have the ability and motivation to complete a rigorous and prolonged postoperative elbow rehabilitation program.20,64,127 Surgical release of the elbow has proved to be an effective way to restore motion, both with an open procedure5,8,9,19,21,52,125,126,128-142 and after arthroscopic release143-151. Good functional results after an open release for posttraumatic stiffness have been described in several case
Figure 2. The mechanism of the “Instrument zu dem Krumme Arm” (“Instrument for the crooked arm”) that was recommended by the German surgeon Hans von Gersdorff in 1517 to address elbow stiffness is the same as that of today’s static progressive turnbuckle splints. (Reproduced from von Gersdorff, H. Feldbuch der Wundartzney. 1st ed. Strassburg: Getruckt durch Joanne Schott, 1517.)
series\textsuperscript{5,8,9,19,21,52,125,126,128-142}, with an average minimal improvement in ulnohumeral motion from 21° up to a maximum average improvement of 66°.\textsuperscript{9,21}

Results of arthroscopic release have been reported less widely, and only few papers\textsuperscript{143-145,148} report results for posttraumatic stiffness separately from those for stiffness originating from other causes. In the ones that do report results separately\textsuperscript{143-145,148} average improvements from 29°\textsuperscript{145} up to 70°\textsuperscript{144} have been reported. Although the safety of arthroscopy is still being studied, in particular with regard to iatrogenic nerve damage, the application of this approach may be extended to even the most severe contractures. The choice between both techniques depends on the extent of the pathology and the experience of the surgeon.\textsuperscript{107} The need for articular reconstruction, as is usual after an intra-articular fracture, is an indication for open release, because articular involvement makes an arthroscopic release more difficult. In addition, previous anterior transposition of the ulnar nerve may preclude use of the anteromedial portal and as a consequence be a contraindication for arthroscopic release.\textsuperscript{152,153}

Other treatment modalities include an interposition arthroplasty when extensive loss of the articular surface is present, especially in younger patients.\textsuperscript{9,89,103,107,154-158} In older patients with very stiff or ankylosed elbows with extensive articular involvement, a total elbow arthroplasty may be considered.\textsuperscript{89,107,155,157}

A young age\textsuperscript{9,136} and arthrosis\textsuperscript{19} have been associated with less favorable outcomes after a contracture release, whereas patients with heterotopic ossification due to burns or head injury seem to have better functional outcomes\textsuperscript{8,53}. However, Bae and Waters\textsuperscript{139} reported results of contracture release in adolescents that were virtually similar to those reported for adults. The timing of surgery has also been associated with the outcomes. The longer the intervention is delayed, the more contracted muscles and tendons become the articular cartilage may also suffer, particularly when there is complete ankylosis of the elbow.\textsuperscript{53} Therefore, patients should preferably be treated within 1 year after onset of stiffness, as better functional results may be expected then.\textsuperscript{21,51,53}

\textit{Open Contracture Release}

Depending on the plane of elbow contracture, the location of previous elbow incisions, the need for nerve decompression, and the location and extent of heterotopic ossification, the surgeon can choose between medial, lateral, and anterior approaches. Either a posterior midline incision or separate medial and lateral incisions will permit both posteromedial and posterolateral arthrotomies and access to the ulnar nerve and anterior elbow via deep lateral and medial approaches.\textsuperscript{7} Separate medial and/or lateral skin incisions may be useful to avoid skin flap devascularization in the case of previous incisions or if there is concern about the integrity of the soft tissue covering the elbow. Avoidance of injury to the median, radial, posterior interosseous, and ulnar nerves is of utmost importance.\textsuperscript{64}
Good results have been described with use of a lateral approach, often referred to as the lateral column procedure. It is a highly versatile approach, although the ulnar nerve will often need to be exposed on the medial side to ensure its safety. The lateral column procedure may be used to address extrinsic contracture of the anterior and posterior capsules with articular involvement of the radiohumeral joint. If articular involvement requires attention to structures other than the radiohumeral joint, this exposure is inadequate. A medial approach may be used to address limited medial articular pathology with involvement of the ulnar nerve, presence of heterotopic bone on the medial side, and ossification or deficiency of the medial collateral ligament (MCL). Although an advantage of this approach is the direct view on the ulnar nerve, a drawback is that the radial nerve is at risk at the depth of exposure on the far side anteriorly. The median nerve is farther away from the capsule than the radial nerve. This limited exposure may not be effective when there is articular involvement.

An anterior approach, which has been reported in several articles for the correction of flexion contractures, has only very limited indications and may only be used for an isolated flexion contracture with normal full flexion and no evidence of bony abnormalities at the olecranon or in the olecranon fossa. Neurovascular structures are at risk when using the anterior approach, and an additional posterior release may frequently be needed. Regardless of the approach that is used, every attempt is made to preserve the lateral collateral ligaments and the anterior oblique band of the MCL. This greatly facilitates rehabilitation and virtually eliminates the potential for postoperative instability. Only in long-standing and very severe cases may a partial release of the anterior oblique band of the MCL and the lateral collateral ligaments be indicated.

The most common complications of open contracture release include neuropathies, infection, and recurrence of elbow stiffness and/or heterotopic bone.

Lateral column procedure

Either a lateral or midline posterior incision is used, fasciocutaneous flaps are elevated and started proximally, and the lateral supracondylar ridge of the humerus is exposed by reflecting the extensor carpi radialis longus (ECRL) anteriorly off the humerus and the triceps off the humerus posteriorly. The dissection is continued for 2 to 3 cm distally through the common extensor tendon from the epicondyle in a line toward Lister’s tubercle. This generally passes in the interval between the ECRL and the extensor carpi radialis brevis (ECRB), along the anterior edge of the extensor digitorum communis. The entire anterior soft tissues are then reflected anteriorly off the capsule, which can then be excised. The release should continue right to the level of the collateral ligaments. The coronoid and radial fossae are cleaned, and spurs and loose bodies are removed. On the posterior side of the elbow, the
triceps is reflected posteriorly from the distal humerus and dissected off the capsule. The capsule is elevated from the humerus, and the olecranon fossa is cleared of spurs and loose bodies. When dissecting medially, it is safe to expose the ulnar nerve through a separate medial exposure (by raising the medial skin flap). The nerve runs along the medial border of the triceps adjacent to the intermuscular septum. It is exposed by following the plane of dissection under the triceps medially to the intermuscular septum, just proximal to the elbow, then exposing between the septum and the triceps. The nerve can then be exposed along its course and retracted while the capsule and scar are excised with the nerve in direct view. Although this approach is quick and obviates a medial skin flap or separate medial incision, the ulnar nerve may frequently need to be transposed anteriorly to prevent delayed onset of ulnar neuropathy by compression of the nerve in the cubital tunnel (Fig. 3). \[^{52,161}\]

**Figure 3.** A lateral approach may be used to address extrinsic contracture of the anterior and posterior capsules with intrinsic involvement of the radiocapitellar joint. (A) A lateral interval is identified between the triceps posteriorly and the ECRL anteriorly, and dissection continues 2–3 cm distally. (B) The anterior soft tissues are reflected off the capsule, which can then be excised. (C) The release of the anterior capsule continues to the level of the medial collateral ligaments. Radial and coronoid fossae are cleaned, and spurs and loose bodies are removed. (D) Subsequently, the triceps is reflected posteriorly from the distal humerus and dissected off the capsule. The capsule is elevated from the humerus, and the olecranon fossa is cleared out. (Reproduced with permission from the Mayo Foundation.)
Medial column approach

The medial column approach\textsuperscript{162} is conceptually similar to the lateral column procedure. The medial antebrachial cutaneous nerve is protected and the ulnar nerve is freed up and transposed anteriorly. The anterior half of the origin of the flexor pronator muscles are reflected from the medial supracondylar ridge. From there, the common flexor-pronator tendon is split longitudinally for 2 cm distally. The brachialis and the anterior portion of the flexor-pronator group are dissected subperiosteally off the anterior humerus and capsule from proximal to distal. The capsule can then be excised. If there is concern about the safety of the radial nerve, a separate limited exposure can be made on the lateral side as described above to resect the lateral capsule under direct vision. The posterior release from the medial side is identical to that described for the lateral column procedure, except that the ulnar nerve must be first transposed. If there is difficulty to release the posterolateral capsule to restore adequate flexion, a separate lateral exposure may be required (Fig. 4).

\textbf{Figure 4.} A medial approach may be used to address medial articular pathology with involvement of the ulnar nerve, heterotopic ossification on the medial side, and ossification or deficiency of the MCL. The ulnar nerve is at direct view using this approach. It is conceptually similar to the lateral approach. The anterior half of the origin of the the flexor pronator muscles are reflected from the medial supracondylar ridge, and from there, the common flexor-pronator is split for 2 cm distally. The brachialis and the anterior portion of the flexor-pronator group are dissected subperiostally off the humerus and the capsule. The capsule can then be excised. (Reproduced with permission from the Mayo Foundation.)

Anterior approach\textsuperscript{19,132}

A curvilinear anterior skin incision is used, starting proximally at the lateral side and continuing distally on the medial side. The structures in the anterior aspect of the elbow are exposed, taking care to protect the medial and lateral antebrachial cutaneous nerves. The brachial artery is identified and protected together with the median, radial, and musculocutaneous nerves. Starting medially, an interval between the flexor muscle origin and the biceps tendon is developed. Using a blunt retractor, the brachialis muscle is dissected from the joint capsule. A curved clamp is then passed from medial to lateral in the interval between
the brachialis muscle and the capsule. The interval between the biceps tendon and the brachioradialis is then exposed, and the interval between the brachialis and the capsule is further developed by blunt dissection. Placing a retractor deep to the brachialis allows direct visualization of the entire anterior capsule, which can then be excised entirely. Sometimes, sharp release of the brachialis may be needed to increase extension. The wound is closed over suction drains and a bulky dressing and plaster splint are applied.

Heterotopic bone

Surgical resection of heterotopic bone is only indicated when the bone blocks motion and is a technically challenging procedure. Anterior heterotopic bone most commonly forms beneath the brachialis muscle and is not continuous with the anterior articular surface. For resection of anteriorly located heterotopic bone, a medial, lateral, or combined medial and lateral approach may be chosen. In case of extensive anterolateral ossification, it is important to identify the radial nerve and the posterior interosseous nerve. The median nerve is most commonly protected by the brachialis muscle. Motion-limiting heterotopic bone in the region of the proximal radioulnar joint requires special attention. The normal cortices of the proximal forearm bones need to be defined, and iatrogenic injury to the lesser sigmoid notch of the proximal ulna should be avoided. Posterior heterotopic bone is often in continuity with the joint, beneath the triceps, and most commonly leads to ankylosis. Resection of posteriorly located heterotopic bone requires elevation of the triceps from the olecranon. If there is posteromedial involvement, extra attention should be paid to the ulnar nerve. After the resection of the heterotopic bone, the surgeon continues with the elbow capsular release as described above.

Complete bony ankylosis is a uniquely challenging problem, because the joint may be entirely encased in bone. The capsule is usually distinct from the heterotopic bone anteriorly but not posteriorly. It may be difficult to identify the junction between the heterotopic bone and the original articular anatomy. An osteotome is used to resect the heterotopic bone in layers, until the joint is encountered; quick and sharp blows with the osteotome will usually separate the heterotopic bone from the underlying host bone along the anatomic planes. Some gentle manipulation is needed intraoperatively. Because of the risk of an iatrogenic fracture, this must be performed with great care. The limited force (applied with 2 fingers) is placed close to the elbow. A hinged external fixator may be considered when there is a tendency for the elbow to subluxate or dislocate after excision. Synostosis that is limited to the radial head or neck level may best be treated with radial head resection. Results of resection of a proximal radioulnar synostosis and complete bony ankylosis are not as promising as are the results of excision of nonbridging heterotopic bone.
Arthroscopic Contracture Release

Only a small number of retrospective case series have been published over the past decades.\textsuperscript{143-150} At the present time, arthroscopic release is best indicated in limited contractures without complicating factors such as the presence of heterotopic bone or neuropathies. Arthroscopic release of the stiff elbow should only be performed by surgeons with a high level of experience and training. In spite of difficulties and risks that are associated with arthroscopy, indications and techniques are evolving rapidly. A factor that complicates the procedure is the limited intra-articular volume capacity that results from the capsular contracture.\textsuperscript{165,166} This can obscure access and visualization of the joint\textsuperscript{145} and puts the neurovascular structures at risk for iatrogenic injury by instruments\textsuperscript{165}. Surgeons should therefore be aware of the special techniques that are being developed when using the arthroscopic approach to address stiff elbows. Some authors\textsuperscript{106,167} recommend the use of retractors in the joint to facilitate the arthroscopic release of the capsule. This will add to visualization and may permit more complex contractures to be addressed safely, without damage to nerves. The surgeon may have to use multiple portals for the scope, shaver/cutter, and the retractors.

Release of the posterior capsule\textsuperscript{168}

A view is established (with the scope in the posterolateral portal and the shaver in the posterior portal, or the scope in the direct midlateral and/or the shaver in the posterolateral portal) by debriding the olecranon fossa. The capsule is elevated from the distal humerus with use of a shaver or periosteal elevator, which further increases the working space. A retractor may be used to maintain this space. In case of synovitis, a synovectomy is performed. Osteophytes and loose bodies are removed, and subsequently the posterolateral capsule is resected with a shaver or radiofrequency ablation device, which is most easily done through the posterolateral portal. If there remains a lack of flexion, the posteromedial capsule is released as well, and if needed, the posterior band of the MCL may also be released. Given the anatomic location of this band near the cubital tunnel, the ulnar nerve is at significant risk when this release is performed. Identification of the ulnar nerve (arthroscopically or through a small incision\textsuperscript{167}) during the posteromedial release is paramount, retractors should be used, and release should be performed along the olecranon as the nerve is closer to the medial epicondyle than to the olecranon. Eventually, the ulnar nerve may be fully exposed or transposed during or prior to the release.

Anterior capsule release\textsuperscript{168}

The first step, assessing the joint cavity, may be the most challenging part of the procedure. Three anterior portals are established, starting with the scope and shaver in the anterolateral and proximal anteromedial portals\textsuperscript{169-172} and a retractor in the proximal anterolateral portal. If
needed, a second retractor can be inserted through the anteromedial portal. The next step is to create a view and to establish a working space. This involves identifying a sufficient amount of normal articular anatomy to permit orientation and then stripping the capsule off the humerus and supracondylar ridges. A synovectomy is performed and the capsule is debrided. Loose bodies and osteophytes are removed, and abnormal bone is recontoured. The capsule is now clearly delineated as a structure before it is cut. The capsule is divided from medial to lateral with a wide-mouthed duckbill punch, as the plane of dissection between the capsule and the brachialis muscle is more distinct on the medial side. The capsulotomy is continued down to the level of the collateral ligaments on each side, and then the capsulectomy is performed on the medial side, extending from proximal to distal. The final step is the proximal and distal excision of the lateral capsule. During this part of the procedure, the radial nerve, located just anterior from the radial head and between the brachialis and ECRB, is unprotected and at risk (Fig. 5). The efficacy of the procedure may be dependent on the completeness of the capsular excision.

Figure 5. Transverse section of a normal elbow before and after distention. Capsular distention places the nerves away from surgical instruments in the normal elbow. In the stiff elbow, the capsular compliance is limited, and particularly the radial nerve is at risk for iatrogenic injury. (Reproduced with permission from Chantal Lichaa O’Driscoll.)

Interposition Arthroplasty
Whereas total elbow replacement may be a viable option to restore motion and relieve pain in the older and less active patient with severely damaged articular surface, interposition arthroplasty may be indicated to restore function and relieve pain in younger and more active
patients, withstanding the functional demands.\textsuperscript{17,154,156,158,173,174} The goal of interposition arthroplasty is to preserve functional stability and to reduce the likelihood of reankylosis by interposing a substance between the resected bone ends.\textsuperscript{174} Resurfacing materials may include autologous fascia lata from the thigh, autologous skin, or an allograft such as an Achilles’ tendon.\textsuperscript{156,158,173,175}

When the ulnar nerve is symptomatic, a medial interval may be chosen.\textsuperscript{156,176} Otherwise, a lateral interval is used. A posterior skin incision or previous incision may be used followed by development of a Kocher’s interval between anconeus and extensor carpi ulnaris. The origins of the common extensor muscle mass and the lateral ligament complex are released from their origin on the humerus. The anterior and posterior ligaments and capsules are excised. The radial head is preserved if forearm rotation is painless. A burr is used to remove a small amount of bone to contour the articular surfaces of the distal humerus and ulna; this accommodates the Achilles’ tendon allograft and concentric fluid joint motion. However, the medial and lateral trochlear ridges should be left intact, as these add to the inherent stability of the elbow.\textsuperscript{177} Drill holes are placed from posterior to anterior in the distal humerus. The graft is contoured the size of the distal humerus and draped over the trochlea and capitellum, and sutures are placed through the drill holes to secure the graft.\textsuperscript{9,174} Ligaments are repaired; this may be done with suture anchors or excess graft if Achilles’ tendon was used. When an articulated external fixator is applied, only a minimal amount of bone needs to be resected, which helps prevent instability.\textsuperscript{158,178,179} The triceps is reattached, and the interval is closed.

Few articles describe the outcome of interposition arthroplasty. Results have been reported with various success for inflammatory\textsuperscript{158,178} and (post)traumatic conditions.\textsuperscript{9,103,158,176} Elbow instability is associated with a poor outcome.\textsuperscript{103,158,176} Complications may include bone resorption, nerve dysfunction, heterotopic ossification, triceps rupture, instability, infection, seroma formation at the fascial donor graft site, and long-term failure.\textsuperscript{158,173,174} In cases of failed interposition arthroplasty, later revision to a total elbow arthroplasty may result in a satisfactory end result.\textsuperscript{158,180}

**Total Elbow Arthroplasty**

Total joint replacement can be a salvage procedure for very stiff or ankylosed elbows with considerable articular involvement in the older and less active patient, especially if there are no other treatment options available anymore.\textsuperscript{89,107,155} Patients should have reasonable expectations and be able to comply with an intensive postoperative rehabilitation program.\textsuperscript{6} In elbows with posttraumatic contracture, which are often complicated by deficient bone stock, deformity, and capsuloligamentous instability, linked designs are usually recommended.\textsuperscript{6,10,107,155,157,177,181,182} These semiconstrained hinge devices are thought to limit
excessive loading of the bone-cement interface by allowing soft tissues to absorb some of the forces. The technique is challenging and, in the case that no triceps-sparing approach is used, the reattachment of the triceps is crucial. Specific techniques depend on the implants that are used, presence of previous incisions, and the surgeon’s preference. However, in all cases, the ulnar nerve should be identified, released from surrounding scar and soft tissue, and eventually transposed. Aggressive soft tissue release that involves the collateral ligaments, and posterior and anterior capsules, and often includes the origins of the common flexors and extensors, is needed to balance soft tissue distortion of the joints. Adequate bone may need to be resected to optimize the outcome; if there is complete osseous ankylosis, the joint line may be established with a sagittal microsaw or small osteotome to create a space as close to the center of rotation of the ulnohumeral joint as possible to offer the best biomechanical and functional condition for the implant. In addition, it may be needed to resect the radial head and heterotopic bone and to re-create an adequate medullary canal with use of a small burr. Although preoperative presence of heterotopic bone and deformity have been associated with a less favorable outcome, total elbow replacement for the treatment of posttraumatic arthritis is associated with substantial functional improvement and pain relief in most cases. However, complications such as ulnar nerve dysfunction, mechanical failure, loosening, infection, triceps disruption, and fracture (particularly in older women) may be seen frequently and result in the need for revision surgery and eventual unsatisfactory outcomes. Some of these complications may be attributed to the stress that components are exposed to (which may depend on the activity level of patients with posttraumatic arthritis and the typically high number of previous surgeries that patients with posttraumatic arthritis have undergone, which increases the risk for wound complications or infection.

Postoperative Management and Rehabilitation

Although the rehabilitation program for each of the surgical procedures has its unique features, the postoperative management should be aimed at (1) restoring a functional arc of motion, (2) regaining muscle power, and (3) reincorporating the limb into functional activities. Most authors start mobilization of the elbow within 2 days after an open contracture release, which may be enhanced by sufficient pain control. Continuous passive motion (CPM) is used by many authors. However, there have been only 2 studies that investigated the role of CPM in the postoperative management of operative elbow release, one of these presumably being an extended follow-up of the other with new patients added. In both studies, patients had a release for extension loss. In the first study, a significant greater
improvement in flexion (and not extension) was found in patients that used CPM compared with the control group that did not use CPM. This study may have been somewhat biased, as some of the patients that were treated with CPM had had a more extensive release than did patients in the other cohort. In addition, patients in the control group were not mobilized until 10 days postoperatively. In the second study, a significant greater ulnohumeral arc was found in patients that used CPM. In this study, it was not specified after how many days the patients in the control group were mobilized. Patients in the cohort that used CPM had substantially stiffer elbows preoperatively than did patients in the control group. A potential advantage of CPM would be that it can be used to flex and extend the elbow until the extremes of motion that were achieved in the operating room are reached. On the other hand, there has been concern about the formation or recurrence of heterotopic ossification after forceful manipulation of the elbow, as described above. At our institution, CPM is prescribed according to the preference of the treating surgeon. Continuous passive motion should not be used if reconstruction of the ligaments was performed. Further research should define the role of CPM in the postoperative management after elbow contracture release.

Aggressive rehabilitation should be continued at least until no additional gains in motion are made. A static progressive turnbuckle splint or a dynamic splint may be very helpful to restore a functional arc of motion. Some authors recommend the use of NSAIDs or low-dose irradiation postoperatively to prevent recurrence of heterotopic bone.

When an interposition arthroplasty is performed, motion may be started early. The external fixator is removed under anesthesia after about 6 to 8 weeks with examination to determine motion and stability. Gentle manipulation may be performed after removal of the external fixator. In patients who had a total elbow arthroplasty, the rehabilitation program depends on the implant that was used, the status of the triceps tendon, the stability as assessed in the operating room, and the status of the ulnar nerve. In patients that have a linked prosthesis, as is usually the case in the treatment of posttraumatic stiffness, the elbow is rarely unstable. Regardless of the type of prosthesis, however, all patients will have to comply with guidelines for upper-limb restrictions (for instance, a 5-lb lifetime weight limit for lifting). Gentle passive stretching may begin for both flexion and extension after about 6 weeks, and gentle strengthening exercises may be begun after 10 weeks, particularly addressing the triceps. If the triceps was reflected and reattached during surgery, triceps contraction should be avoided for 1 month. If the ulnar nerve was not transposed, compression of the nerve during flexion should be avoided. Static progressive or dynamic splinting is rarely indicated after a total elbow arthroplasty. Return to full activity may be indicated after 12 weeks.

In spite of the lack of knowledge about the pathology underlying the causes of posttraumatic elbow stiffness, the pessimistic attitude toward surgical intervention for stiff elbow that
dominated the orthopedic literature of the 20th century has turned more optimistic over the past 2 decades by the introduction of challenging but relatively safe and effective procedures to restore elbow function. Heterotopic bone can successfully be resected with only little risk for complications and good functional outcomes, unless there is complete ankylosis of the elbow or synostosis of the proximal radioulnar joint.

References


PART II

Elbow Trauma