Developments in Elbow Trauma and Reconstruction

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INTRODUCTION

Elbow trauma is challenging to treat (**Fig 1**). Although many of the current principles of internal fixation in the elbow were introduced by Lambotte in the early part of the last century[1] (**Fig 2**), there are still many unresolved issues. In this paper we review part of the work performed at the Orthopaedic Hand and Upper Extremity Service to summarize the contribution of our institution to recent developments in elbow trauma and treatment.

Figure 1: Reduction of an elbow fracture dislocation in Paris, France 1564 by Dr. Ambroise Pare (1510 – 1590)

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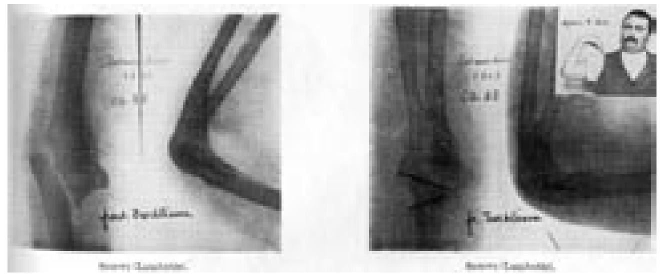

Figure 2: Open reduction and internal fixation of an olecranon fracture in Brussels, Belgium, 1907 by Dr. Albin Lambotte.

RADIAL HEAD FRACTURES

The majority of surgeons agree that partial fractures of the radial head displaced less than 2 millimeters do not benefit from surgery and that displaced fractures of the radial head associated with instability of the forearm or elbow should not be excised without prosthetic replacement. On the other hand, there are many areas of continued debate including operative vs. non-operative treatment for displaced partial head fractures (Mason Type 2) and internal fixation vs. prosthetic replacement for displaced whole head fractures (Mason Type 3).

Partial Radial Head Fractures

Some surgeons advocate operative fixation of a partial (Mason 2) fracture of the radial head when there is greater than 2 millimeters of displacement and the fragment is greater than 30 percent of the articular surface[2]. On the other hand, we and other surgeons have observed that as long as the displaced fragment does not cause a mechanical block to forearm rotation that good elbow function is possible, regardless of the radiographic appearance of the fracture. A recent study from Sweden looked at displaced partial head fractures (Mason 2 according to the modified classification of Broberg and Morrey) and found that over three-quarters of them had good or excellent results according to a very strict grading scale when reviewed decades later.

We have reviewed over 300 partial fractures of the radial head not associated with forearm or elbow instability from the practice of a single surgeon. Among these fractures only 8% percent were felt to be displaced according to the criteria of Broberg and Morrey. In addition, an evaluation of the inter- and intra-rater reliability of the distinction between Mason 1 and Mason 2 (non-displaced and displaced) partial head fractures according to the system of Broberg and Morrey is underway and preliminary results suggest limited reliability. The implications of these findings are as follows: 1) isolated partial head fractures fitting radiograph criteria for operative fixation are uncommon and 2) agreement of different observers on the radiographic indication for surgery may be somewhat unreliable. When considered in combination with the good long-term results of displaced Mason 2 fractures reported from Sweden, this would seem to favor a very limited role for operative treatment of isolated partial radial head fractures.

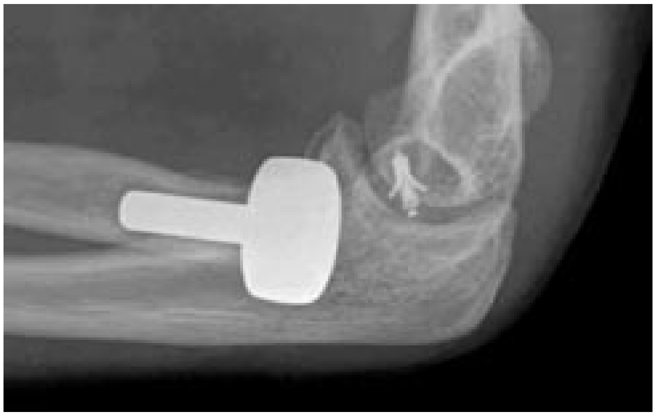

Figure 3: Radiolucency around the stem of the radial head prosthesis was present in 80% of cases.

Fractures of the Entire Radial Head

When we reviewed the results of internal fixation for fractures of the radial head, we found very poor results for complex fractures. In the paper this was defined as greater than 3 articular fragments; however, metaphyseal comminution, impacted and misshapen fragments, lost fragments, and other factors are also important. Early failure, nonunion, and poor forearm rotation were all commonplace[3].

More recently, we reviewed the results of modular metal radial head replacement in fracture-dislocations of the elbow. The prosthesis helped provide immediate stability to all but one elbow. Only one patient had definite "over-stuffing" of the radiocapitellar joint with gapping of the lateral ulnohumeral articulation. Radiolucency around the stem of the prosthesis was present in the vast majority of cases but was not clearly associated with complaints of pain (**Fig 3**). Satisfactory functional results were obtained in about 80% percent of patients. These results are comparable to those reported by Moro and colleagues[4]. From these two series we believe that a modular radial head prosthesis with an intentionally undersized, smooth neck will act as a spacer rather than a true arthroplasty allowing the collateral ligaments to heal and restore stability. The only problems associated with this type of prosthesis appear to be associated with the insertion of a prosthesis that is too long.

Using 3D computed tomography, we sought to identify anatomical landmarks on the proximal ulna as reference points for radial head prosthesis size. We studied three-dimensional computed tomography reconstructions of the intact proximal radius and ulna to better understand the normal relationship between the articular surface of the radial head and the coronoid process of the ulna. The proximal ridge of the radioulnar joint on the ulna, the lateral edge of the coronoid articular surface

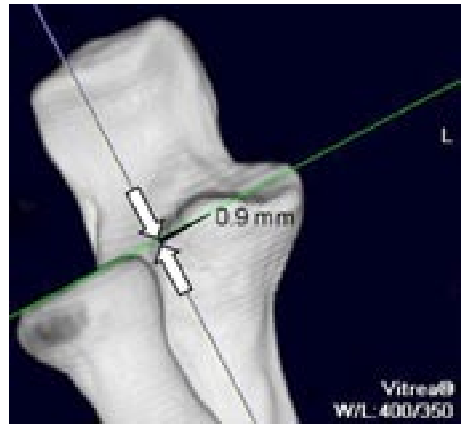

Figure 4: The lateral edge of the coronoid process of the ulna is an easy to identify anatomical landmark to serve as a reference point for radial head prosthesis size. The plane over the proximal surface of the radial head is on average 0.9 mm more proximal than the lateral edge of the coronoid.

Figure 5: The radial head prosthesis should be aligned with the lateral edge of the coronoid to avoid "overstuffing" the radiocapitellar joint.

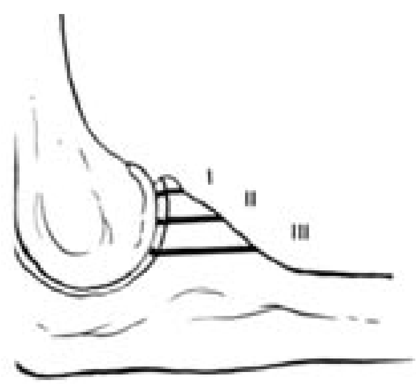

Figure 6: Classification of coronoid fractures based on fracture size according to Broberg and Morrey: Type I, avulsion of the tip of the coronoid process; Type II, a single or comminuted fragment involving 50 percent of the process or less; and Type III, a single or comminuted fragment involving more than 50 percent of the process

was used as an easily identifiable anatomical landmark intraoperatively to serve as a reference point for radial head prosthesis size. Quantification of the relationship between the plane over the articular surface of the radial head and the lateral edge of the coronoid revealed that the radial head is on average 0.9 mm more proximal than the lateral edge of the coronoid (Fig 4). Therefore, to avoid "overstuffing" the radiocapitellar joint the radial head should inserted roughly even, but not more than one millimeter more proud than the lateral edge of the articular surface of the coronoid process of the ulna (Fig 5).

CORONOID FRACTURES

Fractures of the coronoid process of the ulna have long been classified based on the size of the fracture fragment (**Fig 6**) and the presence or absence of an associated elbow dislocation. In the study of Regan and Morrey, none of the coronoid fractures were fixed and larger fractures were associated with worse outcome[5]. Recently, the coronoid process has been recognized as an important stabilizer of the elbow. Biomechanical and clinical studies suggest that even fixation of even small fractures may enhance elbow stability[6-10]. The size and shape of the coronoid fracture fragments will determine the optimal treatment method and can be anticipated based upon the injury pattern.

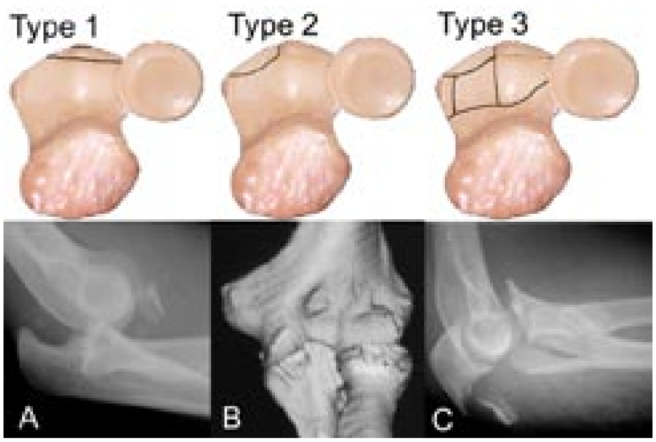

Figure 7: Classification of coronoid fractures based on fracture fragments according to O'Driscoll: Type 1: transverse fractures of the tip of the coronoid; Type 2: fracture of the anteromedial facet of the coronoid process; and Type 3: fracture of the coronoid at its base. Terrible triad injuries are associated with transverse coronoid tip fractures (A), the anteromedial facet coronoid fractures are associated with the varus posteromedial rotational instability pattern (B) and large basal coronoid fractures are associated with olecranon fracture dislocations (C).

Fracture Patterns and Treatment Considerations

We classified 67 fractures of the coronoid process based on fragment size and shape and fragmentation pattern. Two classification systems were used. The system of Regan and Morrey is as follows: Type I, avulsion of the tip of the coronoid process; Type II, a single or comminuted fragment involving 50 percent of the process or less; and Type III, a single or comminuted fragment involving more than 50 percent of the process. The system of O'Driscoll is as follows: Type 1, transverse fractures of the tip of the coronoid; Type 2, fracture of the anteromedial facet of the coronoid process; and Type 3, fracture of the coronoid at its base **(Figure 7A-C)**.

The coronoid fractures were associated with one of four major patterns of elbow fracture-dislocation: anterior, or trans-olecranon, fracture dislocation, defined as a fracture of the olecranon with anterior displacement of the forearm and an intact radial head[11, 12]; posterior olecranon fracture dislocation, or Type A posterior Monteggia injury according to the system of Jupiter, defined as a fracture of the olecranon and coronoid process with posterior displacement of the radius and fracture of the radial head; the terrible triad fracture-dislocation of the elbow, defined as a posterior dislocation of the elbow with fractures of the radial head and the coronoid process; and varus posteromedial rotational instability, defined as a varus subluxation of the elbow with fracture of the coronoid (associated injuries may include the lateral collateral ligament or a fracture of the olecranon).

Among the 24 patients with an olecranon fracture-dislocation, 22 had large coronoid fracture and 2 had small (less than 50%) coronoid fractures (22 RM and OD Type 3 and 2 RM Type 2 or OD Type 1 fractures). All 32 patients with terrible triad injuries had small (less than 50%) coronoid fractures (RM type 2) with one of these being a fracture of the anteromedial facet of the coronoid (31 Type 1 and 1 Type 2 according to O'Driscoll). Among patients with varus posteromedial rotational pattern injuries, nine had small fractures of the anteromedial facet (Type 2 in both systems) and two had larger fractures (Type 3 using both classification systems). The association of coronoid fracture type with injury pattern was strongly statistically significant ($p < 0.001$) for both classification systems.

Large fractures of the coronoid process are strongly associated with anterior and posterior olecranon fracture-dislocations; small transverse fractures with terrible triad injuries; and anteromedial facet fractures with varus posteromedial rotational instability pattern injuries. Awareness of these associations and their exceptions may help guide optimal management of these injuries.

Anatomy of the Anteromedial Facet of the Coronoid

Varus posteromedial rotational elbow injuries are a distinct type of elbow fracture-dislocation that must be recognized and adequately treated to restore good elbow function. This injury pattern is characterized by varus angulation of the elbow without dislocation, and fracture of the anteromedial facet of the coronoid process. Isolated fractures of the anteromedial facet, with concomitant lateral collateral ligament injury, are unstable and despite its seemingly small size needs to be fixed to prevent instability problems (**Fig** 8).

Figure 8: Fracture of the anteromedial facet of the coronoid and concomitant lateral collateral ligament injury: the Varus Posteromedial Rotational Instability pattern as described by O'Driscoll. Despite its seemingly small size needs to be fixed to prevent instability problems

The role of the anteromedial facet of the coronoid process in elbow instability and the vulnerability of the facet is well understood if one considers the bony anatomy of the coronoid process and it's relation with the proximal ulna. The coronoid process of the ulna serves as an anterior buttress in conjunction with the radial head to prevent posterior dislocation of the elbow. The coronoid process is shifted medially with respect to the midline of the trochlear groove of the olecranon. The average distance between the center axis of the trochlear notch and the most medial edge of the anteromedial facet was 7.2 millimeters (range, 4.5 to 8.9 mm) measured in 21

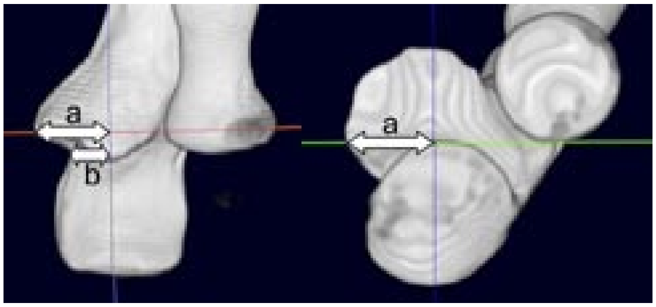

Figure 9: The vulnerability of the anteromedial facet is illustrated by the unsupported portion (a –b = unsupported)—the portion that protrudes as a separate process.

Figure 10: A 45-year-old man fell and had a Type 2 open anterior fracture-dislocation of the elbow. (A) A lateral radiograph taken after splinting of the arm shows anterior displacement of the forearm with the radioulnar relationship maintained. The coronoid remains attached to the diaphyseal ulna, but there is extensive fragmentation of the ulnar metaphysis. (B) The trochlear notch was restored and secured with a long 3.5-mm plate applied to the dorsal surface of the ulna and contoured around the olecranon fossa. Heterotopic ossification formed anteriorly and flexion was limited to 110°. A good functional result was achieved and the patient declined additional surgery.

elbows. The total width of the coronoid process in the defined coronal plane averaged 13.4 mm (range, 8.7 to 16.8). The supported and unsupported anteromedial facet width averaged 3.1 mm (range, 1.0 to 5.0 mm) and 4.1 mm (range, 1.4 to 6.8 mm) respectively. This means that on average 57% (range, 26 to 82%) of the anteromedial facet of the coronoid is unsupported (**Fig 9**). It is not surprising that this relatively vulnerable protrusion from the anteromedial facet of the coronoid is frequently a separate fracture fragment in complex traumatic elbow instability. It merits particular attention during operative treatment to restore elbow stability.

OLECRANON FRACTURE DISLOCATIONS

Fracture dislocations of the olecranon are complex fractures of the proximal ulna or complex combined injuries of the radial head, coronoid, and collateral ligament complexes. Few published reports specifically address these injuries[11-13]. Olecranon fracture-dislocations have been included as part of larger series of elbow fracture-dislocation[14], as part of complex fractures of the proximal radius and ulna[15], posterior olecranon fracture-dislocations were described as part of the spectrum of Monteggia injuries[16, 17] or these injuries were specifically excluded[18, 19]. Failure to recognize these complex injuries as fracture-dislocations of the olecranon may distort the understanding of these injuries.

Anterior and Posterior Olecranon Fracture Dislocations

We defined olecranon-fracture dislocations as: disruption of normal alignment between the distal humerus and the proximal radius and ulna. Over a 7-year period we identified 30 patients with either a change in the alignment of the articular surfaces of the trochlea of the distal humerus and the coronoid process of the ulna, or the radial head and the capitellum, or both.

We evaluated 10 patient with an anterior fracture-dislocation of the elbow and 16 patients with posterior olecranon fracture-dislocation after an average of 6 years. 5 of 10 patients with an anterior injury and all posterior injuries had an associated fracture of the coronoid. Concomitant fracture of the radial head was present in 1 anterior injury and 13 of 16 posterior injuries. Only one patient had a true fracture-dislocation, in the remaining 25 cases the articular surfaces remained opposed.

Operative treatment was done through a dorsal longitudinal skin incision in all anterior fracture-dislocations. The fracture was secured with a 3.5-mm plate and screws (Synthes Ltd, Paoli, PA) in seven patients (Fig 10), a tension band wire construct in two patients, and a tension suture construct in one single patient. A limited-contact dynamic compression plate was used in five patients, a dynamic compression plate was used in one patient, and two stacked 1/3 tubular plates with a supplementary tension band wire was used in one patient. The size of the plate used averaged 10 holes (range, eight - 12 holes). Loosening of the tension band wire construct occurred in one patient and was revised to fixation with two adjacent 3.5-mm pelvic reconstruction plates (each seven holes in length) 17 days after the initial operation. Four of the five fractures of the coronoid were realigned and secured with one or two screws entering through the dorsal aspect of the ulna, either through the plate or independent of it. The one concomitant radial head fracture was treated by excision of the fragment. All patients were treated with a postoperative dressing that incorporated a posterior plaster splint with the ulnohumeral joint held in 90° flexion and the forearm in neutral rotation.

A dorsal midline skin incision was used also used for the posterior fracture-dislocations. Exposure of the proximal ulna and radius were achieved through separate muscular intervals in all but one patient in whom a Boyd type simultaneous exposure of the proximal ulna and radius was done. In 15 patients, the fracture of the ulna was secured with a 3.5-mm plate and screws (Synthes Ltd), and in one patient a tension band construct was used. A limited-contact dynamic compression plate was used in 11 patients, a dynamic compression plate was used in two patients, and a reconstruction plate was used in one patient. The average length of the plate was nine holes (range, seven - 11 holes). All but one of the plates were applied to the dorsal surface of the proximal ulna, and the reconstruction plate was applied to the lateral surface. All of the Regan and Morrey Type 3 fractures were realigned and secured using one or two screws entering the dorsal surface of the proximal ulna either through a hole in the plate or independent of it. The Type 2 fracture of the coronoid was not secured. The fracture of the radial head was treated with open reduction and internal fixation with a plate and/or screws in four patients, excision or partial excision of radial head in five patients, and was not specifically addressed in four patients. The lateral collateral ligament was reattached to the lateral epicondyle in two patients.

Patient with anterior fracture dislocations had slightly better functional results in term of range of motion; flexion-extension arc of 110° (range, 40° - 140°) versus 95° (range, 50° - 120°) and according to the classification system of Broberg and Morrey; four excellent, five good and one poor result versus five excellent, seven good, one fair and three poor results. Ten patients had radiographic signs of ulnohumeral arthrosis and were associated with inadequate treatment of a coronoid fracture.

Effective treatment of fracture-dislocations of the olecranon requires a stable trochlear notch. The preventable aspects of unsatisfactory results in patients with anterior or posterior injuries were mostly related to malunited coronoid fractures and therefore inadequate restoration of the trochlear notch. Immediate elbow stability can be achieved with secure internal fixation, including the coronoid process, since collateral ligament complexes are relatively spared in olecranon fracture-dislocations.

REHABILITATION OR RECONSTRUCTION OF STIFFNESS

Elbow stiffness is the most common complication of elbow trauma. The dysfunction associated with elbow stiffness has long been appreciated. In 400 B.C Hippocrates stated "If ankylosis should eventually develop, an arm ankylosed in the extend position would be better away (i.e. amputated) for it would be of great hindrance and of little use to the patient".

Operative treatment of elbow stiffness with open or arthroscopic elbow capsulectomy has become well established. Static progressive splinting is often considered prior to operative treatment when standard exercises have not achieved satisfactory elbow motion but it is our impression that these splints are under appreciated and underutilized.

Static Progressive Splinting

We believe that the majority of patients with post-traumatic elbow contractures that plateau with standard range of motion exercises will avoid surgery if they use static progressive splinting to help improve motion.

We retrospectively studied 29 patients that were treated with static progressive splinting over a 3-year period. Adult patients with post-traumatic elbow contractures were included in our study cohort when a standard exercise program was no longer achieving gains in motion. The initial injury was a fracture of the distal humerus in nine patients, a fracture of the radial head in four patients, an elbow fracture-dislocation in fifteen patients, and a simple dislocation of the elbow in one patient. Three patients were treated after the injury alone; fourteen were treated after operative treatment of the initial injury, and twelve after a secondary operative contracture release for post-traumatic stiffness. Splinting was initiated an average of fifty-five days (range, 15 to 200 days) after injury or operative treatment.

Pre-splinting the flexion-extension arc averaged 71° (range, 0° - 100°). Post-splinting the arc improved to 112° (range, 20° - 150°). After splinting, all but three patients had a flexion contracture less than 30 degrees and 10 patients (34 %) had less than 130 degrees of flexion. Only three patients opted for an elbow contracture release—two to address heterotopic bone and one with an associated ulnar neuropathy.

Static Progressive Splinting can help achieve a functional arc of motion in patients with post-traumatic elbow contractures. Our study reemphasizes the non-operative treatment option post-traumatic elbow stiffness with custom fitted of the shelf elbow braces. When patients plateau with standard physical therapy, static progressive splinting should be added because most patients will avoid surgery, or will be familiar with the device when they require surgery.

Heterotopic Ossification

Heterotopic ossification has been regarded with trepidation and considered a poor prognostic factor for operative restoration of elbow motion. We compared the results of elbow contracture release in patients with and without heterotopic ossification blocking elbow motion to test the hypothesis that heterotopic bone is associated with diminished elbow motion after release.

Nineteen patients with heterotopic bone restricting elbow motion (but not complete bony ankylosis) were compared with twenty-two patients with capsular contracture alone. The sex, age, initial injuries, percentage of dominant limbs, number of prior procedures, mechanisms of injury, open injuries, polytrauma patients were comparable between groups. The average pre-operative arc of flexion and extension in the patients with heterotopic bone was 52 degrees (range, 5 to 90 degrees) and 52 degrees (range, 10 to 90 degrees) in patients with capsular contracture alone.

After the index procedure, the flexion-extension arc in patients with heterotopic ossification averaged 105 (range, 45 to 105 degrees) and the arc in the capsular release group averaged 86 degrees (range, 0 to 135 degrees). The average improvement in F-E arc was 53 degrees (range, -20 to 107 degrees) for the HO patients and 34 degrees in the capsular release group (range, -20 to 75 degrees). The difference in improvement after the first release was significant ($p = 0.034$).

Six of 22 patients (26%) in the capsular release group and two of eighteen patients (12%) in the HO group had a second procedure for capsular release. At an average of 24 months follow-up (range, 6 to 63 months), the final arc of flexion and extension averaged 105 degrees in the patients with heterotopic bone (range 40 to 145 degrees) and 96 degrees (range, 45 to 135 degrees) in patients without HO. The average improvement in flexion-extension arc was 53 degrees (range, -20 to 107 degrees) in the HO group and 43 degrees (range, -15 to 80 degrees) in the capsular contracture group. The greater improvement in range of motion in patients with heterotopic ossification compared to patients with capsular contracture alone was not significant with the numbers available ($p = 0.122$).

Heterotopic bone restricting motion (but not causing total ankylosis) is associated with more predictable and perhaps slightly better (not worse) restoration of motion after elbow contracture release.

EVALUATION OF ELBOW FUNCTION

Elbow and upper extremity function can be assessed with standardized outcome measurements such as the physician-based evaluation instruments Mayo Elbow Performance Index, the Broberg and Morrey rating or the American Shoulder and Elbow Surgeons Elbow Evaluation Instrument or the patient-based upper extremity specific health status questionnaire Disabilities of Arm, Shoulder and Hand. The Short Form-36 questionnaire quantifies general health status.

Our hypothesis was that complaints of pain have a strong and overwhelming influence on these scores and that they are therefore less sensitive to objective measures of elbow dysfunction.

Pain Dominates Measurements of Elbow Function

During a five-year period, health status data and elbow ratings have been systematically gathered on patients at various stages of recovery as part of various prospective and retrospective trials. Inclusion criteria for this study were: 1) prior intra-articular fracture of the elbow, 2) 18 years of age or older, 3) date of evaluation greater than six months since the injury or the latest surgery, 4) absence of interpositional or prosthetic arthroplasty. One hundred and four patients satisfied these criteria and represent the study cohort.

Multivariate analysis of variance and regression modeling was used to identify which of the factors—age, gender, injury to dominant side, distal humerus fracture, time since last surgery, number of operations subsequent to the original treatment of the injury, the total arc of flexion and extension, the total arc of pronation and supination, ulnar neuropathy, arthrosis, and pain—account for the variability in scores derived from these measures—in other words, which factors have the strongest influence on the final score.

Pain alone accounted for 66% of the variability in Mayo Elbow Performance Index scores, 59% of Broberg and Morrey scores, and 57% of American Shoulder and Elbow Surgeons Elbow Evaluation Instrument scores. Models that included other factors accounted for only slightly more of the variability in these scores: from 66% to 73% for Mayo Elbow Performance Index scores, 59% to 79% for Broberg and Morrey scores, and 57% to 79% for American Shoulder and Elbow Surgeons Elbow Evaluation Instrument scores. With regard to the health status measures: 36% of the variability in Disabilities of Arm Shoulder and Hand (DASH) scores could be accounted for by pain alone and 45% by pain and range of motion with other factors having a negligible influence. Thirty-five percent of the variability in the SF-36 Physical Component Scores and 25% of SF-36 Mental Component Scores was due to pain alone, with the best possible models accounting for 45% of the Physical Component scores and 35% of the Mental Component Scores. Models that did not include pain accounted for a more limited proportion of the variability of the scores: 22% for the Mayo Elbow Performance Index, 41% for Broberg and Morrey scores, 41% for American Shoulder and Elbow Surgeons scores, 17% for Disabilities of Arm Shoulder and Hand scores, 12% for Physical Component Summary scores, and 3% of Mental Component Summary Scores.

Pain has a very strong influence on both physician-rated and patient-rated quantitative measures of elbow function. Consequently, these measures may be strongly influenced by the psychosocial aspects of illness that have a strong relationship to complaints of pain and they may undervalue objective measures of elbow function such as mobility. It may be advisable to evaluate pain separate from objective measures of elbow function in physician-based elbow ratings in order to increase our understanding of the influence of objective elbow dysfunction on health status.

CONCLUSION

Displaced partial radial head fractures that fit radiographic criteria for operative treatment are uncommon, there is disagreement between observers regarding the amount of displacement, and non-operative treatment seems to achieve good long-term results. Complex fractures of the radial head associated with elbow or forearm instability should be repaired or replaced with a metal prosthesis. A smooth, loose-fit, modular metal prosthesis can achieve good results provided that it is not too long, or "overstuffed". This can be monitored using the lateral edge of the coronoid as a reference point when the proximal surface of the radial head implant should be even with.

Fractures of the coronoid occur in specific patterns that are strongly associated with the overall injury pattern. The anteromedial facet of the coronoid is particularly vulnerable and is fracture when subjected to varus stress. Large coronoid fractures are usually associated with olecranon fracture-dislocations—restoring the contour and dimensions of the trochlear notch is necessary for a good result.

Post-traumatic stiffness can often be treated effectively with static progressive splinting. When operative release is performed, the presence of heterotopic bone blocking motion (but not causing ankylosis) is associated with somewhat better recovery of motion. Measures of elbow function and health status are both driven primarily by pain with objective factors such as motion having a more limited influence.

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