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Management of anteromedial coronoid fractures according to a protocol focused on instability assessment provides good outcomes with infrequent need for coronoid fixation

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Background: Anteromedial coronoid fractures (AMCFs) are associated with persistent elbow instability and post-traumatic arthritis if managed incorrectly. It is unclear exactly which AMCFs require surgical intervention and how to make this decision. The aims of this study were to report outcomes of AMCFs managed using a protocol based on reproduction of instability using radiographic and clinical testing and to ascertain a threshold size of AMCF associated with instability.
Methods: Forty-three AMCFs were studied. Thirty-two patients formed the primary study group (group A). All were treated using a protocol in which the decision to perform coronoid fixation was based on the presence of radiographic or clinical evidence of instability. Functional outcomes (Oxford Elbow Score), radiographic outcomes, complications, and reoperations were collected, and a receiver operating characteristic curve analysis was performed to assess the optimal coronoid fracture height to recommend coronoid fixation. The results were compared with a historical group of 11 patients with AMCFs not treated according to the protocol (group B).
Results: Of the patients, 23 had an isolated AMCF and 20 had a concurrent radial head injury. Complete nonoperative treatment of the elbow was performed in 16 patients (37%) (11 of 32 [34%] in group A vs. 5 of 11 [45%] in group B, $P = .46$). In 10 patients (23%), only repair of the lateral collateral ligament was performed (9 in group A and 1 in group B), whereas 8 patients (19%) underwent repair of the lateral collateral ligament and radial head fixation or replacement (6 in group A and 2 in group B). Acute coronoid fixation was performed in 9 patients (21%) (6 in group A and 3 in group B). At a mean follow-up of 20 months (range, 12-56 months), group A showed a significantly better Oxford Elbow Score (42 vs. 31, $P = .02$), lower complication rate (3 of 32 [9%] vs. 8 of 11 [72%], $P < .001$), and lower reoperation rate (1 of 32 [3%] vs. 6 of 11 [54%], $P < .001$) than group B. Persistent instability was found in 6 patients in group B and none in group A. The receiver operating characteristic curve analysis demonstrated 6.5 mm to be the optimal AMCF size for surgery to prevent persistent instability.
Conclusion: Patients treated according to a protocol in which preoperative reproduction of instability determined the degree of surgical intervention had good clinical and radiographic outcomes. Our study demonstrated that AMCFs > 6.5 mm are likely to be more unstable and require intervention. If these principles are followed, a specifically defined subset of AMCFs can be treated nonsurgically without adverse outcomes.

On application, local ethics approval was granted by the research department (Brighton and Sussex University Hospitals) without further review by the ethics committee as this study was part of ongoing service evaluation.

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The coronoid process is the primary bony stabilizer of the ulnohumeral joint, and consequently, coronoid fracture size, location, and morphology are predictive of the degree and pattern of elbow instability.[1,11] O'Driscoll et al[10] drew specific attention to the importance of the anteromedial (AM) part of the coronoid in their classification system. This region of the coronoid, along with the lateral collateral ligament (LCL), resists varus forces across the ulnohumeral joint[10] (Fig. 1). AM subtype 3 fractures involve the sublime tubercle of the ulna and the insertion of the anterior band of the medial collateral ligament (MCL). These fractures invariably result in ulnohumeral instability; however, uncertainty exists about exactly which subtype 1 and 2 fractures require surgical treatment. The concept of posteromedial varus instability classically entails a varus, internal-rotation subluxation of the ulna relative to the distal humerus that is poorly tolerated because of the frequent varus moment placed on the elbow with activities of daily living. The consequent increase in contact stresses can result in accelerated post-traumatic arthritis if mismanaged.[7] As a result, some authors have advocated aggressive surgical stabilization of all anteromedial coronoid fractures (AMCFs) to prevent this complication.[10,12,16] These are relatively new concepts, and many AMCFs managed in the past without intervention or without recognition have not necessarily resulted in debilitating post-traumatic arthritis. Furthermore, some authors have reported successful management of AMCFs without any intervention; hence, deciding exactly which coronoid fracture needs fixation remains a key question.[3,8,17]

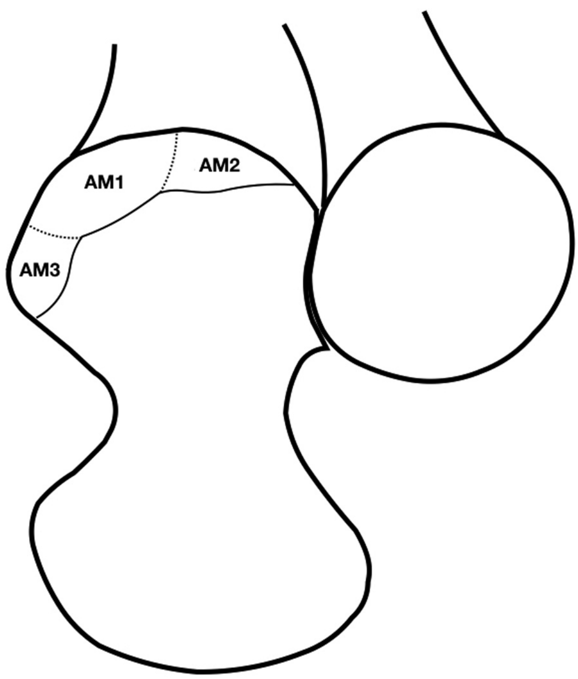

Figure 1 O'Driscoll classification of anteromedial coronoid fractures. Anteromedial subtype 1 *(AM1)* involves the anteromedial rim. Anteromedial subtype 2 *(AM2)* involves the anteromedial rim and tip region (most common). Anteromedial subtype 3 *(AM3)* involves the sublime tubercle and anteromedial rim with or without the tip region (least common).

In a biomechanical study, Closkey et al[4] suggested that coronoid fractures < 50% did not result in elbow instability under axial loading, although they did not consider the influence of combined loads and associated injuries. Pollock et al[13] specifically studied the effect of AMCF size in conjunction with LCL insufficiency on elbow kinematics, suggesting that LCL repair alone may be sufficient to stabilize the elbow when the coronoid fracture is <5 mm. A fundamental problem is the difficulty in reliably measuring coronoid fracture size. There is variation in the cartilage thickness of the coronoid[14] (meaning the size may be underappreciated), variation in computed tomography (CT) protocols, and variation in how imaging is interpreted by clinicians. In addition, both the coronoid fracture height and width are likely to be important, and small measurement errors are significant if fracture size alone is the determinant of treatment. Furthermore, the LCL, posterior MCL, anterior MCL, and posterolateral capsule all contribute to rotatory stability, with varying degrees of injury in a given fracture-dislocation.[5,7] These injuries are further compounded or compensated for by the integrity of the anterior capsule and common flexor and extensor muscles, which are not included in biomechanical work.

It would seem that, although all factors including AMCF size, displacement, and morphology, as well as associated injuries, are likely to be critical in decision making, a definitive constellation of injuries to predict adverse outcomes remains elusive and is unlikely to be the same for every fracture-dislocation. Our intuition has been that reliance on absolute radiographic measurements of coronoid size and shape would be prone to error, especially across a range of treating surgeons, and that answering the question "Is this elbow stable?" is more important for decision making.

Our practice has been to use radiographic and clinical tests to determine whether static or dynamic instability is present and to use this information to determine which components of the injury require surgical intervention. These tests are first performed in the outpatient setting and can be repeated intraoperatively for those patients who require surgery to help guide a reconstructive plan for each injury. This protocol has been developed and followed by the senior author (J.P.), prior to which, in our institution, management of patients with an AMCF was performed by a variety of surgeons without a defined management algorithm.

The primary aims of this study were (1) to describe the outcomes of patients treated using a systematic management protocol with instability assessment at its core and (2) to assess whether this protocol was able to safely identify which patients could be treated with and without fixation of their AMCFs. The secondary aim was to compare the outcomes of patients treated using this strategy with those of other patients treated in our institution by surgeons not following this method of assessment and decision making.

Methods

Patients and inclusion and exclusion criteria

The focus of this study was coronoid fractures caused by rotatory instability; hence, patients with coronoid fractures associated with other types of instability, such as trans-olecranon fracture-dislocation or Monteggia variant, were excluded. Using our departmental trauma database, we identified 120 adult patients presenting to our institute with such a coronoid fracture between January 2014 and January 2019. The minimum follow-up time for inclusion was 12 months.

Patients without CT scans to allow accurate fracture classification were excluded, and only O'Driscoll AM subtype fractures (Fig. 2)[10] were included in the final study. Patients treated for chronic coronoid reconstruction were also excluded. After exclusions, 45 patients with a fracture involving the AM facet were identified. We excluded 2 of these patients as they were completely lost to follow-up. The remaining 43 patients made up the study group. Of these patients, 32 were treated by the senior author (J.P.) according to the protocol described later (group A) and 11 were managed by other surgeons not following the same decision-making process (group B). A comparison was made between the clinical and radiographic results of the 2 patient cohorts.

Outcome measures

Patient-reported outcomes collected were as follows: return to preinjury work and sports, visual analog scale score for pain, Oxford Elbow Score (OES), and patient satisfaction. Range of motion (measured using a goniometer), complications, and reoperations were recorded and reported for all patients.

Radiographic outcomes were assessed using plain anteroposterior and lateral radiographs by all authors and via clinical examination by the senior author (J.P.). Joint incongruity was used to denote residual instability, and the presence of post-traumatic degenerative changes in the ulnohumeral joint was quantified using the Broberg and Morrey grading system.[2] The joint was classified as incongruent in the presence of a widened ulnohumeral joint and/or malalignment of the radiocapitellar articulation on a true lateral view of the elbow and in the anteroposterior plane by asymmetry of the ulnohumeral joint space (Fig. 3).

Figure 2 Example of anteromedial subtype 2 fracture included in study.

Classification and assessment of coronoid fracture size

Coronoid fractures were classified according to the O'Driscoll classification system (Fig. 1). CT scans were performed using a slice thickness of 1 mm with axial, coronal, sagittal, and 3-dimensional reconstructions. Only fractures involving the AM region of the coronoid were included in this study. Measurement of coronoid fragment height was performed from the CT scan using the largest articular height of the AMCF. Classification and size measurement were performed by all authors and repeated at a 3-month interval to assess interobserver and interobserver reliability. A receiver operating characteristic (ROC) curve was constructed to establish whether the data indicated a threshold AMCF size that would necessitate surgical fixation to prevent joint instability.

Instability assessment protocol

The instability assessment protocol is used to diagnose the presence of elbow instability through imaging and clinical examination. Initial assessment is performed in the outpatient setting. Patients without reproducible evidence of elbow instability are treated nonsurgically. Patients with radiographic or clinical evidence of instability are taken to the operating theater, where the degree of surgical intervention is determined by repeating the tests intraoperatively. Figure 4 outlines the protocol summarized later.

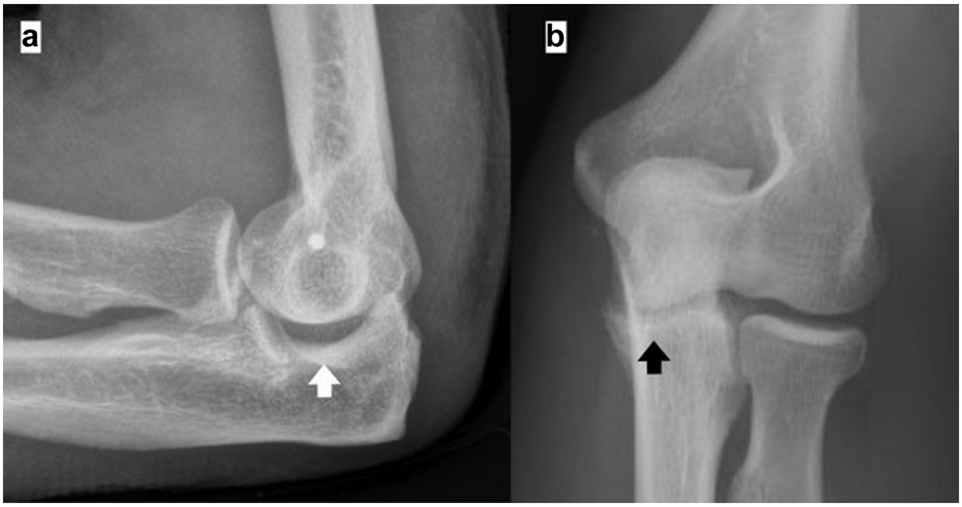

Figure 3 **(a)** Ulnohumeral incongruity on lateral radiograph (*white arrow*) in patient who underwent lateral collateral ligament repair without coronoid fixation. This is sometimes referred to as the "drop sign." **(b)** Ulnohumeral incongruity on anteroposterior radiograph in group 2 patient who was inappropriately treated nonoperatively. One should note the varus attitude of the elbow with relative narrowing of the medial ulnohumeral joint space and secondary degenerative changes (*black arrow*).

Imaging

All patients presenting with a suspected coronoid fracture on plain radiographs undergo a CT scan with 3-dimensional reconstruction to allow assessment of the coronoid fracture morphology and the presence of associated bony injuries. Patients with static ulnohumeral joint incongruity seen on plain radiographs or CT scans are offered surgical treatment (Fig. 5). Patients with an associated injury such as a radial head fracture that warrants surgical intervention on its own merit are also offered surgery. A decision on whether to treat the AMCF is made intraoperatively using fluoroscopy and the clinical tests described later.

Clinical examination for instability

Examination for instability is performed in the clinic within the first week after injury. Inspection of the elbow is performed first to look for swelling and the pattern of bruising. Lateral bruising is considered a red flag as it implies an extensive lateral ligament injury with breaching of the lateral capsule, common extensor tendons, and lateral fascia and is rare compared with medial bruising, which is a more common, nonspecific finding.

Range of motion is assessed with the patient in the supine position with the arm overhead to allow gravity compression of the ulnohumeral joint. Grinding, clunking, or crepitus during this motion is suggestive of joint instability.

Two specific tests are performed to assess instability further and to determine the need for surgical intervention. The posterolateral rotatory drawer (PLRD) test is used to assess LCL competence as described by O'Driscoll[9] and quantified according to our system (Table I). Grade 0 and 1 elbows are suitable for nonoperative management, whereas grade 2 and 3 lesions are considered for surgical intervention. A positive test finding indicates insufficiency of the LCL.

The varus stress (VS) test is performed with the patient in a seated position and the shoulder abducted to 90° to create a gravitational varus torque on the elbow.[3] With the examiner supporting the humerus, an active and passive flexion-extension motion of the elbow is performed. A positive test finding is denoted by locking, grinding, or crepitus during this motion or if the patient has mid-arc pain that is not present with supine overhead motion. When positive, the crepitus is easily palpable over the medial aspect of the joint and frequently audible. A positive test finding indicates marked varus instability with contribution of the AMCF to this instability.

Patients with either a positive PLRD test finding or positive VS test finding are offered surgical treatment to address the LCL

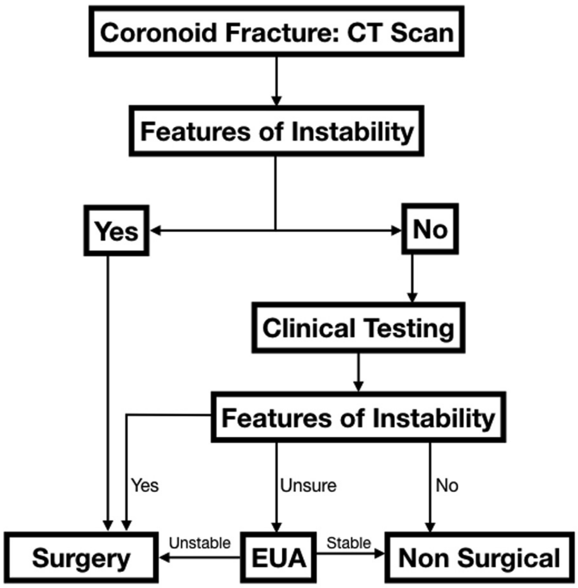

Figure 4 Flowchart summarizing treatment protocol followed in group A patients. *CT*, computed tomography; *EUA*, examination under anesthesia.

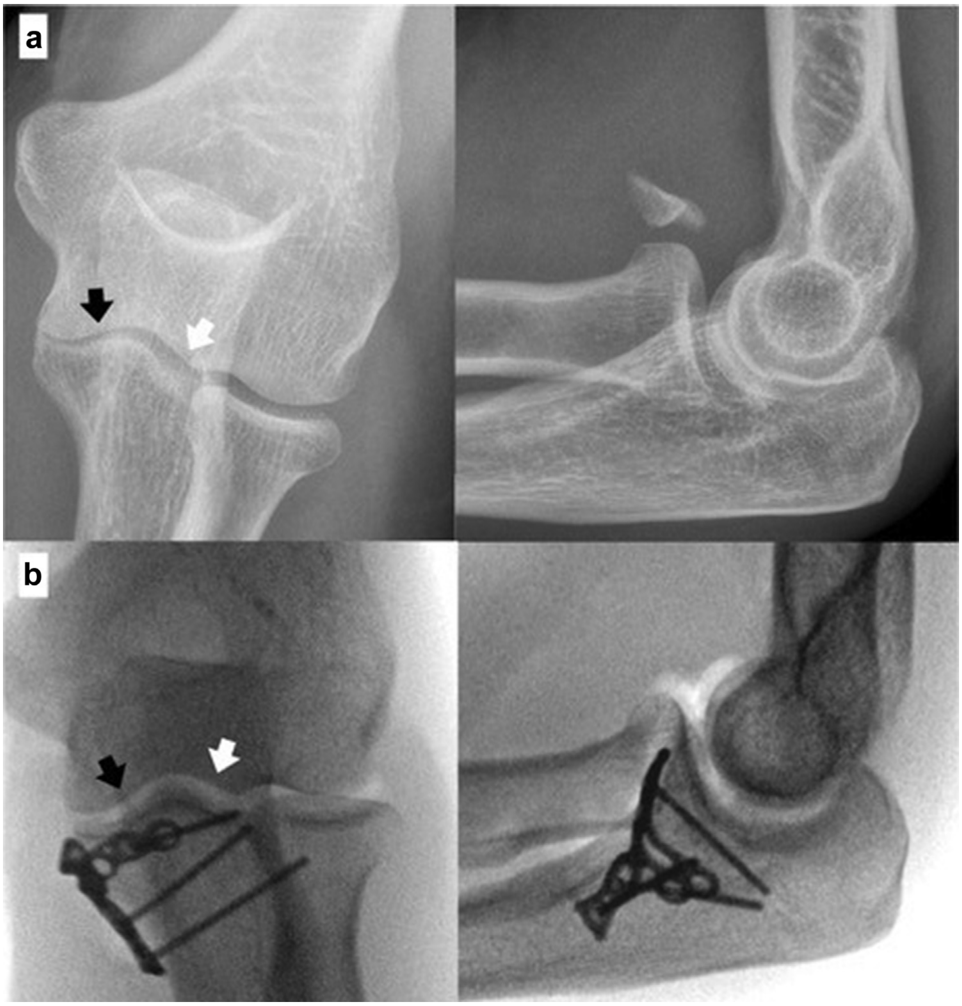

Figure 5 (**a**) Anteroposterior and lateral radiographs of patient with anteromedial subtype 2 fracture. On should note the static varus subluxation on the anteroposterior radiograph, indicated by relative narrowing of the medial ulnohumeral joint space *(⬆)* compared with the normal lateral ulnohumeral joint space *(white arrow)*. The presence of static instability seen on imaging was an indication for fixation of the anteromedial coronoid fracture. (**b**) Following buttress plating, a congruent joint space has been restored as indicated by the *arrows*. The lateral collateral ligament was repaired with an all-suture anchor (radiolucent).

Table I Grading of PLRD test

Grade	Findings
0	Stable elbow—no reproducible laxity
1	Physiologic laxity (equal to opposite elbow)
2	Pathologic laxity (greater than opposite elbow)
3	Instability—reproducible clunking and subluxation

PLRD, posterolateral rotatory drawer.

and/or AM coronoid fragment. Patients with negative test findings and none of the other indications for surgery outlined are treated nonoperatively (Fig. 6).

Nonoperative protocol

For patients treated nonoperatively, immediate active range of motion is commenced. This is performed in the supine position with the arm overhead using gravity to provide a compressive joint reaction force. Varus torque is limited by avoiding shoulder abduction $>45°$. Active motion is preferred to provide dynamic stability from the muscles crossing the elbow. Patients are followed up with serial radiographs and clinical examination at 2 and 8 weeks from the initial examination. Physiotherapy is commenced as part of the protocol, but the emphasis is on active motion performed by the patient in the first 8 weeks. No bracing or splints are used.

Surgical protocol

Surgery is performed in a stepwise manner to address each structure contributing to instability. If the VS test finding is positive preoperatively or during examination under anesthesia or if static varus subluxation is seen on imaging, the AMCF is fixed first using either an open medial approach or an arthroscopic technique depending on fracture morphology and displacement. If the VS test finding is negative but the PLRD test finding is positive, the lateral

Figure 6 (**a**) Images of a 24-year-old male patient with an isolated anteromedial coronoid fracture measuring 7.2 mm in height with 2 mm of displacement treated in group A. Nonoperative treatment was chosen as there was no evidence of joint incongruity and the findings of the posterolateral rotatory drawer and varus stress tests were negative. (**b**) At 2-year follow-up, the elbow is congruent with no arthritis and the patient has full pain-free function and motion.

structures are addressed first. The procedures include repair of the LCL with or without fixation or replacement of the radial head according to the fracture pattern. If the AMCF is fixed first (VS test finding positive), the lateral structures are addressed second.

Stability is reassessed using fluoroscopy and intraoperative clinical examination. The PLRD test finding should be negative after LCL repair. If positive, the radial head fixation and LCL repair are reassessed. If the VS test finding is still positive or there is evidence of joint gapping on fluoroscopy, the AMCF and MCL (anterior and/or posterior band) are repaired.

If any residual instability exists and there is certainty regarding the quality of repairs performed, a salvage stabilizing procedure such as application of an external fixator may be considered. Rehabilitation after surgery is performed in exactly the same manner as for nonoperative patients following an active, supine overhead protocol with avoidance of varus torque (shoulder abduction) and without the use of splints or braces.

Statistical methods

Categorical variables and baseline demographic data are described using frequencies and percentages. Continuous variables are presented using means and standard deviations (SDs). Nonparametric tests (Mann-Whitney U and χ^2 tests) were used to test for differences between groups. The Pearson product-moment correlation coefficient (r) was used to measure the level of intraobserver and interobserver reliability for coronoid fracture fragment size. Correlations of 0.7-0.89 were regarded as good and $\geq$0.9, as excellent. The Cohen κ method was used to calculate the intraobserver and interobserver reliability of the O'Driscoll classification, in which $\kappa \leq 0.2$ indicates slight; 0.21-0.4, fair; 0.41-0.6, moderate; 0.61-0.8, substantial; and 0.81-1, almost perfect. $P < .05$ was considered statistically significant. For the ROC curve analysis, the area under the curve (AUC) was calculated and considered highly significant if >0.8. Statistical analysis was conducted using SPSS software (version 25; IBM, Armonk, NY, USA).

Results

Coronoid fracture characteristics

All patients had a fracture involving the AM facet of the coronoid. According to the O'Driscoll classification, 4 fractures (9%) were AM subtype 1, 36 (84%) were AM subtype 2, and 3 (7%) were AM subtype 3. In 29 patients (67%), the fractures were displaced by >2 mm. There was no significant difference in the distribution of fracture types between groups A and B. Both interobserver reliability and intraobserver reliability for the coronoid fracture classification were fair (κ = 0.232 and κ = 0.343, respectively).

The mean fracture fragment size measured on CT was 6.5 mm (range, 2.9-14.2 mm; SD, 2.4 mm). Interobserver reliability and intraobserver reliability were both good (r = 0.80 and r = 0.88, respectively).

Associated bony injuries

An isolated AMCF was found in 23 patients (53%). Radiographically documented evidence of an elbow dislocation was noted in 15 patients (35%). Moreover, 20 patients (47%) had an associated radial head fracture.

There was no significant difference in the distribution of injuries between groups A and B. An isolated AMCF was observed in 18 of 32 patients (59%) in group A vs. 5 of 11 (45%) in group B (P = .26); dislocation, 10 of 32 (31%) in group A vs. 5 of 11 (45%) in group B (P = .12); and radial head fracture, 14 of 32 (41%) in group A vs. 6 of 11 (55%) in group B (P = .34).

Interventions

Individual group interventions are summarized in Table II. Complete nonoperative treatment of the elbow was performed in 16 patients (37%) (11 of 32 [34%] in group A vs. 5 of 11 [45%] in group B, P = .46). Of the surgically treated patients, 10 (23%) underwent only repair of the LCL (9 in group A and 1 in group B) whereas 8 (19%) underwent repair of the LCL and radial head fixation or replacement (6 in group A and 2 in group B).

Regarding fixation, 9 patients (21%) received acute coronoid fixation (6 in group A and 3 in group B). Moreover, 7 patients underwent fixation with either screws or a buttress plate (6 in group A and 1 in group B), and 2 patients in group B underwent fixation with suture anchors and transosseous sutures. Of 9 coronoid fixations, 8 were performed through an open approach whereas 1 was performed arthroscopically.

Of the 23 patients with an isolated AMCF, 13 (56%) underwent nonoperative treatment, 3 (13%) underwent coronoid fixation and LCL repair, and 7 (35%) underwent only LCL repair. In 4 patients (17%), a medial ligament repair was performed in conjunction with another procedure to the coronoid, LCL, or radial head.

Clinical outcomes

Individual group characteristics and results are shown in Table III. The mean follow-up period was 20 months (range, 12-48 months). The follow-up time of patients in group A was significantly shorter (18 months in group A vs. 27 months in group B, P = .02), although the minimum follow-up period for both groups was 12 months.

In group A, the mean flexion-extension arc of motion was 130° (range, 80°-140°; SD, 14°) and the mean rotation arc was 162° (range, 70°-170°; SD, 15°). There was no significant difference in range of motion in any plane between the 2 groups.

The mean OES was significantly higher in group A than in group B (42 vs. 31, P = .02). No significant difference in the visual analog scale score for pain was found between the groups (1.4 in group A vs. 2.8 in group B, P = .14).

Complications and reoperations

Complications and reoperations are summarized in Table IV. In group A, there were 2 complications and 1 reoperation in the same patient. Complex regional pain syndrome and capsular contracture developed in this patient, requiring open capsular release 18 months after index surgery. One other patient in group A developed symptomatic contracture in the ipsilateral shoulder which was treated successfully with hydrodilatation and physiotherapy. Comparison of the 2 groups showed significantly fewer complications in group A than in group B (3 of 32 [9%] vs. 8 of 11 [72%], P < .001) and significantly fewer reoperations in group A than in group B (1 of 32 [3%] vs. 6 of 11 [54%], P < .001).

Table II Interventions performed in each group

Intervention	Group A (n = 32), n (%)	Group B (n = 11), n (%)	P value
Nonoperative	11 (34)	5 (45)	.7
LCL repair	9 (28)	1 (9)	.4
LCL repair and radial head fixation or replacement	6 (18)	2 (18)	>.999
Coronoid ORIF and LCL repair with or without radial head fixation or replacement	6 (18)	3 (27)	.6
MCL repair (with other procedures)	2 (6)	2 (18)	.2

LCL, lateral collateral ligament; *ORIF*, open reduction–internal fixation; *MCL*, medial collateral ligament.

Table III Comparative group characteristics

	Group A (n = 32): protocol	Group B (n = 11): non-protocol	P value
Mean age, yr	47.9 ± 18	54.7 ± 17	.26
Sex			
Male	22	7	.1
Female	10	4	.1
Mean follow-up, mo	18.3 ± 6	27.8 ± 12	.02*
Documented dislocation	10	5	.12
Radial head fracture	14	6	.34
Isolated coronoid fracture	18	5	.26
Coronoid fracture subtype			
1	4	0	.56
2	27	9	>.999
3	1	2	.1
Mean coronoid fragment size, mm	6.6 ± 2.5	7.6 ± 2.7	.31
Fracture displacement >2 mm	22	7	>.999
Mean OES	42.4 ± 7	31.9 ± 11	.02*
Mean VAS score for pain	3.2 ± 3.0	1.5 ± 1.8	.14
Mean flexion arc, °	130 ± 14	112 ± 27	.2

OES, Oxford Elbow Score; *VAS*, visual analog scale.
* Statistically significant ($P < .05$).

In group B, 6 of 11 patients (54%) had evidence of persistent instability. Of these, 2 underwent delayed coronoid fixation and ligament reconstruction; 1 was managed with application of a hinged external fixator; 1 underwent manipulation and reduction under anesthesia; and 1 required total elbow arthroplasty. One patient declined further surgery despite evidence of persistent instability and post-traumatic arthritis. There were no incidences of symptomatic heterotopic ossification (HO), although minor asymptomatic HO was seen in 11 of 32 patients (34%) in group A and 6 of 11 patients (54%) in group B. All instances of HO were related to the ligament origins or radial head, rather than occurring within the anterior or posterior compartments.

Radiographic outcomes

All patients with clinical features of persistent instability had radiographic evidence of joint incongruity and/or degenerative changes. Of the patients, 35 (81%) had no evidence of post-traumatic arthritis, 5 (12%) had mild evidence of arthritis, and 3 (7%) had severe arthritic changes. All 3 patients with severe arthritis were in group B with evidence of persistent instability.

Relationship between instability and coronoid fracture size

Although there was no significant difference in AMCF size between the groups, the size was significantly greater in patients who underwent coronoid fixation than in those who did not (10.7 ± 2.7 mm vs. 6.1 ± 1.9 mm). ROC curve analysis was performed to determine whether there was a threshold of AMCF size to recommend surgical intervention. ROC curve analysis was performed for both group A alone (on the basis that there were no cases of instability following treatment, ie, the correct fractures were chosen for operative treatment) and for groups A and B combined. In group B, some fractures appropriate for treatment were not treated and resulted in persistent instability. Both curves are shown in Figure 7. For group A, the optimal threshold for fixation of the coronoid according to ROC curve analysis was a fracture >8.5 mm. For the whole group, the optimal threshold was a fracture >6.5 mm. For the group A analysis, to achieve maximum sensitivity (to pick up all cases requiring fixation using the protocol described), the optimal AMCF size for fixation was 6.5 mm. For the group A ROC curve, the AUC was 0.93, and for the curve including all patients, the AUC was 0.77. Both curves demonstrated statistical significance ($P < .001$ and $P = .001$, respectively).

Discussion

In this study, the majority of patients with a coronoid fracture involving the AM facet were able to be successfully managed either nonoperatively or with selective treatment of other injuries excluding the coronoid. Decision making for the main study cohort (group A) was based primarily on whether the elbow exhibited signs of instability using radiographic and clinical parameters. There were no cases of persistent instability, and patients had excellent outcomes with this approach, indicating that it is a safe method for the evaluation and management of AMCFs.

Table IV Complications and reoperations in each group

	Group A (n = 32): protocol, n (%)	Group 2 (n = 11): non-protocol, n (%)	*P* value
Complications	3 (9.3)	8 (72)	<.001*
Persistent instability	0 (0)	6 (54)	<.001*
Complex regional pain syndrome	1 (3)	0 (0)	.9
Symptomatic stiffness	1 (3)	1 (9)	.4
Shoulder stiffness	1 (3)	0 (0)	.9
Iatrogenic radial neck fracture	0 (0)	1 (9)	.2
Reoperations	1 (3)	6 (54)	<.001*
Delayed coronoid ORIF	0 (0)	2 (18)	.06
Ligament reconstruction	0 (0)	2 (18)	.06
External fixation	0 (0)	1 (9)	.2
Total elbow replacement	0 (0)	1 (9)	.2
Contracture release	1 (3)	0 (0)	.9
Other			
Asymptomatic HO	11 (34)	6 (54)	.2

ORIF, open reduction–internal fixation; *HO*, heterotopic ossification.
* Statistically significant ($P < .05$).

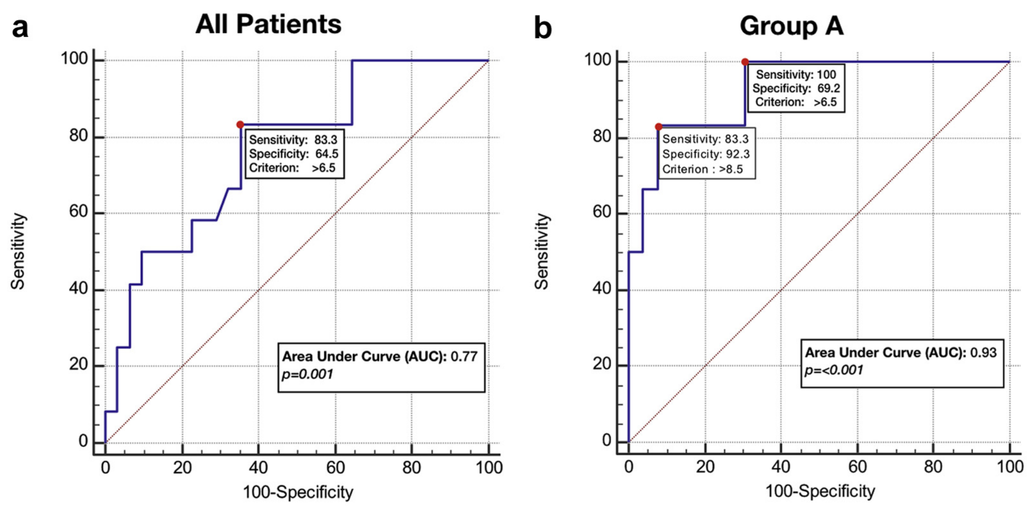

Figure 7 Receiver operating characteristic curves used to assess optimal coronoid fracture height to consider anteromedial coronoid fracture fixation. **(a)** Curve calculated from all patients (groups A and B). This curve suggests that the optimal height for fixation is 6.5 mm. **(b)** Curve calculated from only group A patients in whom decision making and the treatment protocol yielded good results and no persistent instability. The optimal tradeoff between sensitivity and specificity was a threshold of 8.5 mm; however, to achieve 100% sensitivity (to not miss any anteromedial coronoid fracture that may benefit from fixation), we suggest using 6.5 mm as the threshold to consider surgical fixation.

The diagnosis of elbow instability through radiographic and clinical evaluation was the cornerstone of the protocol used, and this practice was adopted because of the lack of consensus in the literature regarding which AMCFs would lead to instability and post-traumatic arthritis. Clearly, some fractures can be treated nonsurgically, and others need aggressive surgical intervention to achieve a congruent elbow with no adverse sequelae. Although the message of this study is not to rely solely on fragment size as a determinant of treatment, it is logical that the larger an AMCF is, the more likely it contributes to instability, particularly if displaced. Indeed, it was evident that patients who underwent coronoid fixation had a significantly larger coronoid fracture than those who did not undergo fixation (10.7 ± 2.7 mm vs. 6.1 ± 1.9 mm, $P = .007$). The data collected as part of this study in relation to coronoid fracture size gave us the opportunity to test the assumption that AMCF size is integral to decision making regarding fixation, and to our knowledge, this is the first time this has been done in a clinical series. On the basis of the ROC curve analysis, it can be recommended that an AMCF measuring >6.5 mm in height should be considered for fixation, along with repair of the LCL and treatment of any radial head pathology if present. This figure is slightly greater than the 5-mm threshold suggested in the biomechanical work of Pollock et al,[13] who concluded that 5 mm was the threshold size to consider fixation; however, a number of cases with larger AMCFs (up to 11.3 mm) were treated successfully either nonoperatively or with LCL repair alone when following the successful group A protocol. Hence, recommending fixation of fractures > 6.5 mm would mean some fractures may be fixed unnecessarily; however, we believe that the consequences of missed, persistent instability are so severe that sensitivity (capturing all possible coronoid fractures that might need fixation) should be prioritized over specificity. For this series, a threshold value of 6.5 mm yields 100% sensitivity for group A, which means that if the protocol is followed, no AMCFs that require fixation will be missed. The AUC for these recommendations was very high, indicating good reliability of this cutoff based on our data.

A limitation of relying on size measurements is the potential for interobserver and intraobserver variability in making the measurements, as well as the variability in cartilage height between individuals.[14] We tried to control for this through interobserver and intraobserver reliability testing, which demonstrated good reliability for each. A more important limitation of relying on fragment size is that stability is a factor of the bony and soft tissue constraints. It is important to re-emphasize that we believe that clinical and radiologic testing is still crucial, particularly when deciding on nonoperative treatment.

We are not the first group to report that a large proportion of AMCFs can be managed nonoperatively. Foruria et al[6] reported nonoperative management of 28 isolated coronoid fractures using a protocol involving cast immobilization for 3 weeks. The mean coronoid fracture size in their study was 5.7 mm (range, 3.7-7.9 mm), which was slightly smaller than that in our study. In our protocol, in contrast to their protocol, we chose not to immobilize patients with the rationale that if the elbow was not stable enough to commence early motion, it required surgical intervention. Early motion may have been possible in our patients because of the emphasis on LCL repair in those with a positive posterolateral drawer test finding. Ten such patients underwent isolated LCL repair, all with good outcomes, in group A. This finding demonstrates the importance of the LCL in preventing varus and rotatory instability. It is interesting to note that, in the study by Foruria et al, 2 patients had persistent evidence of LCL insufficiency requiring delayed reconstruction despite cast immobilization. We favor early LCL repair as short-term cast immobilization may be insufficient to allow robust ligament healing and because acute LCL repair is simple to perform and results in immediate resistance to varus torque.[13]

Some authors have favored the surgical treatment of all AMCFs. Park et al[12] reported on 11 patients with an AMCF: 2 O'Driscoll AM subtype 1 fractures underwent LCL repair alone, and 9 AM subtype 2 fractures underwent both LCL repair and coronoid open reduction–internal fixation, through an open medial approach and buttress plating. They made no reference to the possibility of nonoperative treatment and based their decision making on fracture classification. Ulnar nerve complications developed in 2 of 9 patients (22%) who underwent coronoid fixation, which supports our assertion that blanket treatment of all AMCFs has the potential to result in unnecessary morbidity even with diligent identification and protection of the ulnar nerve.

Rhyou et al[15] reported a systematic approach similar to ours for the management of 18 AMCFs. They also used the VS test and favored coronoid fixation for fractures >5 mm unless the fragments were comminuted. An interesting finding was that they noted that almost all fractures requiring fixation were >6 mm, which is similar to the ROC curve findings in our study. Rather than the PLRD test, they used magnetic resonance imaging scanning to diagnose LCL deficiency. Seven patients underwent LCL repair only; however, only 1 patient was treated nonoperatively. Several patients were also treated with coronoid fixation but no ligament repair. Magnetic resonance imaging is not swiftly accessible in many health care systems, and radiologic abnormalities of the ligaments do not necessarily correlate with symptomatic instability. The fact that we treated more patients nonsurgically may be because we made the decision to operate based on the presence of reproducible instability rather than imaging findings alone.

Ring and Doornberg[16] reported on 18 AMCFs, concluding that surgical treatment of the coronoid was recommended for even very small AM fragments. Seven patients in their study were treated nonsurgically, and in 4 of these patients, persistent varus instability and post-traumatic arthritis developed. However, in their study, 16 of 18 fractures (89%) were either displaced subtype 2-3 fractures including the sublime tubercle or basal fractures of the coronoid (subtype 3). All had preoperative radiographic evidence of marked instability on radiographs, with examples shown in their article. Our recommendation is also to treat patients with radiographic evidence of instability surgically; however, their results and recommendation to treat all fractures surgically, in our opinion, should not be extrapolated to the more frequent AM subtype 2 fracture, which was most common in our study and that of Foruria et al.[6] This discrepancy in recommendations between experienced surgeons in different articles emphasizes why we recommend teaching how to recognize instability through radiographic and clinical measures rather than basing treatment solely on fragment size, shape, or classification.

A unique feature of this study is the comparison of outcomes between the patients treated according to the protocol in group A and those treated separately in group B. This was not the primary aim of the study; however, we were able to identify a separate group of patients treated in our unit retrospectively through our trauma database and believed it would be of value to compare outcomes. These patients (group B) had significantly worse outcomes in terms of the complication rate and patient-reported outcome measures. We attribute their inferior outcomes to the fact that they were treated by general trauma surgeons at a time when there was less awareness of the role played by AMCFs in elbow stability, as well as less understanding of its natural history, imaging assessment, and management. Treatment was therefore determined without a uniform logical or evidence-based approach.

A limitation of our study is that group B included fewer patients and had a longer follow-up time. This was because these patients were identified retrospectively through our trauma database, whereas patients in group A were all managed by 1 surgeon (J.P.) with prospective data collection. The trauma database used captures all fractures treated surgically and nonsurgically; hence, it is our belief that a number of AMCFs were completely missed or ignored in the past. A few such patients have presented subsequently for salvage treatment, but many are likely to have had satisfactory outcomes. Despite including fewer numbers, we believe the drastically different results in group B highlight the importance of recognizing, assessing, and managing AMCFs in a rigorous manner to avoid complications.

Six patients in group B had persistent instability. Closer analysis of these patients was performed to try to understand whether any specific features of their injury or management led to the persistent instability. Of these 6 patients, 5 had a displaced AMCF; however, the mean fragment size and proportion of patients with a displaced fracture were no different compared with the rest of the cohort. In fact, it was the one patient with a minimally displaced fracture in whom the most profound arthritic changes developed, with the need for elbow arthroplasty. Even at the time of arthroplasty, the patient had a strongly positive PLRD test finding with a ‘‘bald’’ lateral epicondyle seen intraoperatively. Had this patient been treated in group A, we believe the LCL ligament insufficiency would have been addressed early, likely with a different outcome.

High-grade post-traumatic degenerative changes developed in 4 of the 6 patients (67%) in group B with persistent instability. In contrast, only 2 patients (6%) in group A showed the development of minor seemingly asymptomatic degenerative changes. Patients with degenerative changes had a significantly longer mean follow-up period (33 months vs. 19 months, $P = .05$); however, in all patients with high-grade degenerative changes, these changes began to develop <12 months after injury. This finding substantiates the view that early and progressive degenerative changes are likely to develop in patients with persistent instability if mismanaged. It is also likely on the basis of our data that long-term post-traumatic arthritis is unlikely to develop in patients without signs of persistent instability, whatever their treatment, although we do not have long-term imaging to confirm this. In 2 of the 6 patients (33%) with persistent instability, post-traumatic arthritis did not develop at radiographic follow-up of 17 and 19 months, respectively. It is possible that progressive arthritic changes would develop with time in these 2 patients. Anecdotally, though, we have seen both patients referred with frank, chronic posteromedial varus instability for up to 9 years without arthritis and patients with arthritis requiring urgent reconstruction within months. It has been demonstrated in cadaveric studies that progressive elevation in ulnohumeral contact pressures occurs with sequential tearing of the LCL and posterior MCL in association with an AMCF.[7] It may be that a ‘‘full house’’ of bony and ligamentous injuries is required to produce post-traumatic arthritis or that the variability in initial chondral impaction and comminution is underestimated. This would be useful to study in more depth.

Of the 9 patients who underwent coronoid fixation in our study, 7 had good outcomes. Both patients with poor outcomes were in group B. One patient underwent fixation of the coronoid with suture anchors, and the other, with transosseous sutures. Both patients had persistent instability requiring revision surgery. In group A, coronoid fixation was performed either with ≥ 2 independent screws or a buttress plate and screws. We believe that suture fixation of any sort does not provide sufficient anatomic rigidity to withstand the forces placed on the AMCF during varus loading and should be avoided.

A critique of this study could be that we included patients with associated injuries rather than just an isolated AMCF. These injuries may reflect different patterns of elbow instability. However, it is our belief that in assessing any fracture-dislocation, the stability of the elbow needs to be scrutinized by asking the same questions: (1) Is the LCL compromised, and (2) does the coronoid contribute to varus instability? If the radial head is fractured, this needs to be treated to restore lateral column integrity, but following this, the same 2 questions apply. Hence, we believe this protocol is applicable to all fractures involving the AM part of the coronoid that a treating surgeon might consider for fixation.

Another potential study limitation is that the PLRD test and VS test, which are integral to the treatment strategy, were performed by a specialist elbow surgeon, and hence, the general reproducibility of these tests and their interpretation could be questioned. To our knowledge, studies assessing this point have not been performed, although we find these tests simple to teach, reproducible, and reliable even in the awake patient as compared with other elbow instability tests.

Conclusion

Patients with an AMCF should undergo rigorous radiographic and clinical examination for evidence of reproducible instability. There should be an appreciation that AMCFs >6.5 mm are likely to be more unstable and require intervention. Instability should be addressed in a stepwise manner with re-evaluation after each surgical intervention. If these principles are followed, a specific subset of AMCFs can be treated nonsurgically without adverse outcomes.

Disclaimer

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