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ORIGINAL PAPER

Good outcome using anatomically pre-formed buttress plates for anteromedial facet fractures of the coronoid—a retrospective study of twenty-four patients

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Abstract

Purpose The aims of this retrospective study were to describe the characteristics of anteromedial facet fracture of the coronoid (AMFF) and to determine the outcome following surgery using anatomically pre-formed coronoid buttress plates.

Methods Twenty-four patients underwent surgery for AMFF, using a pre-formed buttress plate, between 2011 and 2017 (20 men, four women), with a mean age of 47.7 years (range, 19–78 years) and a mean post-operative follow-up of 3.7 years (range, 12–86 months). Fracture classification, injury pattern, accompanying injuries, post-operative range of motion, and revision rate were noted. Post-operative radiographs assessed union, arthritic change, and joint articulation. Joint function was quantified using the Mayo Elbow Performance Score (MEPS), the Oxford Elbow Score (OES), and the Disabilities of the Arm, Shoulder, and Hand (DASH) scores.

Results Eleven cases with subtype 2 and 13 cases with a subtype 3 AMFF could be included, of which 15 had an associated rupture of the lateral collateral ligament (LCL) and nine of the medial collateral ligament (MCL). Post-operatively, all cases went to bone union without secondary elbow instability. The mean post-operative range of motion was 125° (range, 90–140°), mean MEPS was 98, mean OES was 43, and mean DASH score was 7. Five patients required repeat surgery within two years due to a limited range of motion; 90% of patients regained their pre-trauma levels of physical activity.

Conclusions AMFF are challenging injuries, frequently associated with lesions to the collateral ligament complex. Using anatomically pre-formed coronoid plates, excellent functional outcomes can be achieved.

Keywords Coronoid fracture · Anteromedial facet · Lateral collateral ligament · Outcome · Elbow · Coronoid · Instability

Purpose

The coronoid process has a primary role in stabilizing the ulnohumeral or elbow joint and forms an anterior buttress that, in combination with the radial head, prevents the elbow joint from posterior dislocation [1–4]. Several structures are connected to the coronoid process, including the anterior part of the medial collateral ligament (MCL) at the sublime tubercle on the medial side of the coronoid, the radial annular ligament, and the anterior capsule and aponeurosis of the musculus brachialis muscle at the tip, emphasizing its eminent role for elbow stability [5]. Although fractures of the coronoid are relatively uncommon, they can be found in 2–15% of the patients with a dislocation of the elbow, whereas isolated fractures rarely occur [6]. For this reason, fractures of the coronoid are often associated with other bony and soft tissue injuries around the elbow [7], which has led to the assumption that coronoid fractures can be seen as pathognomonic for complex elbow instability [8].

Understanding the mechanisms of injury in these lesions might help to predict additional injuries to the other stabilizing structures of the elbow, with the identification of the anteromedial facet being a key element to the elbow stability. According to Ring et al., most cases of anteromedial facet fractures (AMFF) of the coronoid are caused by a varus posteromedial rotational injury force instead of a

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Level of evidence Level IV; Case Series; Treatment Study

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posterolateral rotatory force, which is in contrast with the majority of other destabilizing elbow injuries [9].

Current management recommendations favor the reconstruction of all coronoid fractures associated with elbow instability, regardless of size [6, 10]. Depending on the size as well as the position of the fragments, different surgical options and approaches have been described [11–21]. While visualization and fixation for coronoid tip fractures using an anterior approach might be favorable, it seems inappropriate for anteromedial facet fractures involving the sublime tubercle and for treating concomitant injuries of the MCL [22].

Because the optimal treatment of AMFF of the coronoid remains controversial, the aims of this retrospective study were to describe the characteristics of AMFF of the coronoid and to determine the outcome after treating these fractures with anatomically pre-formed coronoid buttress plates [Fig. 1]. To our knowledge, no other studies have reported on the results using this kind of new fixation device.

Methods

Patients

Patients were selected by searching the patient clinical management system, Medico® (Cerner Health Services GmbH, Idstein, Germany) from 2011 to 2017 for all coronoid fractures, treated with an anatomically pre-formed coronoid plate (Acumed, Oregon, USA). All patients gave informed consent to the surgical procedure and the protocol of the study was reviewed and approved by the Regional Ethics Committee.

Classification of anteromedial facet fracture of the coronoid

The fractures were classified using the O'Driscoll classification system, based on the computed tomography (CT) scans that were taken pre-operatively and confirmed intra-operatively [23]. Fractures with two or more fragments were graded as "comminuted." The fracture patterns were divided into those with posteromedial rotational injuries and with posterior elbow dislocation, from the initial radiographic findings.

Surgical procedure

All surgery was performed with the patient in a supine position under general anaesthesia. Under tourniquet control, either a global posterior incision or separate lateral and medial approaches were used. In trans-olecranon fracture-dislocation (two cases), the proximal ulna fracture was initially reduced by using a dorsal locking compression plate. On exposure of the coronoid fracture, the ulnar nerve was identified and

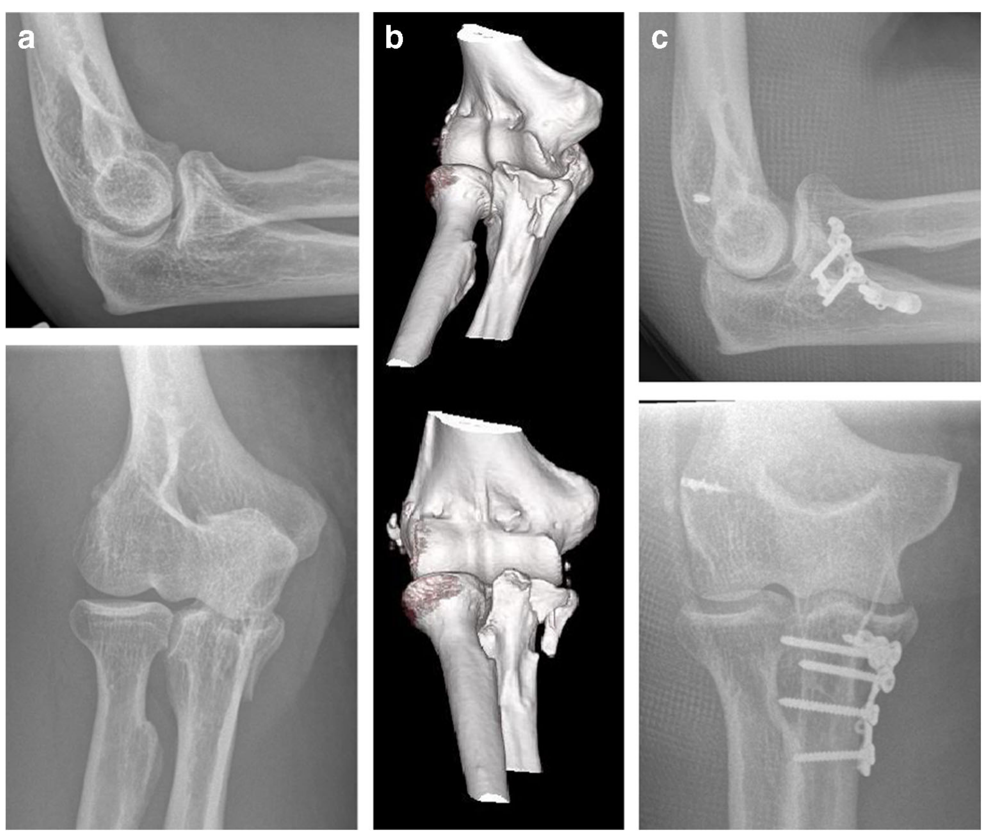

Fig. 1 Imaging findings of the elbow in a 49-year-old man with a comminuted anteromedial facet fracture (AMFF) of the coronoid treated with a pre-formed coronoid plate. **a** A pre-operative lateral radiograph of a 49-year-old man with a comminuted AMFF of the coronoid, subtypes 2 and 3. **b** A preoperative computed tomography (CT) scan showing a comminuted AMFF of the coronoid, subtypes 2 and 3. **c** Postoperative imaging shows excellent reduction with maintenance of the articular alignment

neurolyzed, and a flexor split approach was used in these patients. The reduction was secured by K-wires, as needed.

Depending on the medial extent of the fracture and fragment size, either a plate with sharp prongs or with additional ventral screws and a medial support beam were chosen to provide optimal stability (Fig. 2). After stable coronoid fixation, fractures of the radial head were addressed. In four cases, cannulated screws were used as needed and in one non-reducible case, implantation of a monopolar metallic radial head prosthesis was performed (MoPyc, Tornier, Montbonnot, France). Any associated detachment of the collateral ligaments, the common flexor origin CFO or the common extensor origin (CEO), was fixed using 3.5-mm suture anchors (Arthrex, Naples, USA). The medial collateral ligament (MCL) was repaired, if there was residual instability, using a suture anchor at the humeral site and in cases with ruptures near the sublime area with direct sutures or sutures against the buttress plate. After fixation and ligament repair were completed, stress testing was performed and joint congruency was confirmed under fluoroscopy. In two patients, because of an unacceptable residual instability in extension, a hinged external fixator was required to maintain the concentric joint reduction and allow early range of motion, and the hinged fixator was removed after three weeks.

Post-operative follow-up and evaluation of joint function

Post-operatively, patients wore a protective splint, with the elbow in 90° flexion for the first 3 days. Then, a hinged dynamic elbow brace was applied for passive flexion and extension exercises, from 20° of extension to 120° of flexion. Active non-weight-bearing physiotherapy and passive motion were commenced from the first post-operative day. Varus stress of the elbow (shoulder abduction) was avoided for the first six weeks after surgery.

After a minimum follow-up of one year, the patients were invited for clinical evaluation by an independent experienced orthopaedic surgeon. The range of motion of both elbow joints was tested using a standard goniometer and ligament stability was clinically measured. Post-operative functional outcome was assessed by the Mayo Elbow Performance Score (MEPS) [24]; the Oxford Elbow Score (OES) [25, 26], ranging from 0 to 48; and the German Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, ranging from 0 to 100 with 0 representing a perfectly functioning arm [27, 28].

The level of post-operative pain was rated using a visual analog scale (VAS) questionnaire. If the implanted material was removed at the time of evaluation, the patients were also asked to recall their elbow function before removal. Bony union, failure of the implant, and loss of reduction were evaluated retrospectively, based on the available post-operative follow-up and review of anteroposterior (AP) and lateral radiographs. Radiographic signs of osteoarthritis were rated according to the system reported by Broberg and Morrey, and heterotopic ossification was graded using the classification system developed by Foruria et al. in 2013 [29], which takes both the articular surface (I, preserved/II, damaged) and the loss of motion (A–C) into consideration.

Statistical analysis

Statistical analysis was performed using IBM SPSS version 23 (IBM Germany GmbH, Ehningen, Germany). Mean values were compared using independent *t* tests or the Mann–Whitney nonparametric test when the sample size was small.

Results

Patient characteristics

Between 2011 and 2017, 24 patients (four women and 20 men) with an AMFF of the coronoid process who were treated with an anatomically pre-formed coronoid plate were reviewed. The average patient age was 47.7 years (range, 19–78 years) (Table 1). The injury had occurred to the dominant arm in 14 patients. The cause of the fracture was a fall or a low energy impact injury in 14 cases, a bicycle accident in

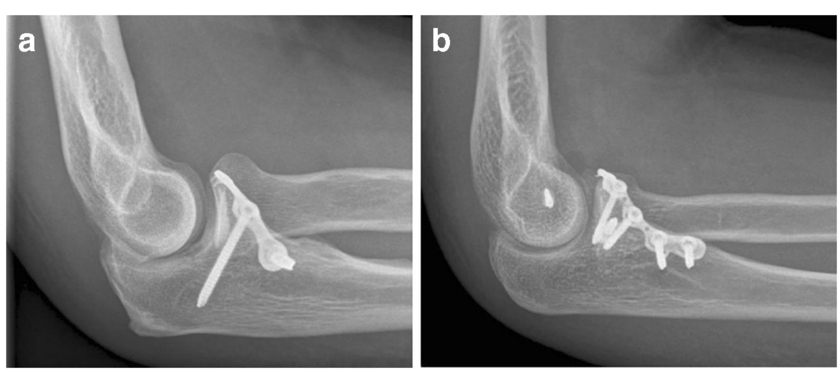

Fig. 2 Lateral radiographs of both types of coronoid plates used for the treatment of anteromedial facet fracture (AMFF) of the coronoid in this study. **a** Treatment of AMFF of the coronoid with a plate with sharp prongs. **b** Treatment of AMFF of the coronoid with a plate with additional supporting screws

Table 1 Summary of patient demographics, injury patterns, and outcomes following surgical treatment of anteromedial facet fracture (AMFF) of the coronoid

No.	Sex	Age	FU	Mechanism	Classification	Configuration	Plate type	LCL	MCL	Radial head	MEPS	OES	DASH	HO	OA	Revision
1	M	50	63	Terrible triad	2.3	C	1	Y	N	0	100	46	1.7	I A	0	
2	M	19	26	Posterior Dislocation	2.2	C	1	Y	Y	0	90	48	0.0	0	0	
3	M	44	58	Posterior Dislocation	2.3	C	2	N	Y	0	100	38	6.7	0	0	Y
4	M	27	12	PMRI	2.2	Non-C	1	Y	N	0	100	39	7.5	0	0	
5	M	49	28	Posterior Dislocation	2.2	C	1	Y	Y	0	100	43	5.8	0	0	
6	W	46	65	Trans-olecranon	2.2	C	2	Y	N	0	85	46	0.0	0	0	Y
7	M	69	17	PMRI	2.2	Non-C	1	N	Y	0	95	47	0.0	I A	0	Y
8	M	41	66	PMRI	2.3	C	1	Y	N	0	100	40	13.3	0	0	
9	M	23	59	PMRI	2.3	Non-C	2	Y	N	0	100	41	4.2	0	0	
10	M	43	67	PMRI	2.2	C	1	Y	N	0	100	42	10.8	0	0	
11	M	57	66	PMRI	2.3	C	1	Y	N	0	95	43	16.7	I A	Grade II	Y
12	M	21	14	PMRI	2.3	C	2	N	Y	0	100	47	0.0	0	0	
13	M	56	13	PMRI	2.3	Non-C	2	Y	N	0	100	43	7.5	I A	0	Y
14	W	50	64	PMRI	2.3	Non-C	2	Y	N	0	100	42	6.7	0	0	Y
15	W	62	29	Terrible triad	2.2	C	1	N	Y	IV	100	48	0.0	I A	0	
16	M	45	87	Posterior dislocation	2.2	C	1	N	N	IV	90	47	0.0	0	0	
17	W	78	36	Trans-olecranon	2.3	C	2	Y	Y	IV	95	37	23.3	0	Grade I	
18	M	62	23	Terrible triad	2.2	C	1	Y	N	IV	100	47	5.8	0	0	
19	M	66	57	Terrible triad	2.3	C	1	Y	Y	IV	95	31	19.2	I A	Grade I	
20	M	47	68	PMRI	2.2	Non-C	1	Y	N	0	100	40	7.5	0	0	
21	M	55	23	PMRI	2.3	C	1	Y	N	II	95	43	5.8	0	0	
22	M	54	66	PMRI	2.3	C	2	N	N	0	100	41	7.5	I A	0	
23	M	38	18	PMRI	2.3	Non-C	2	N	N	III	100	46	6.7	0	0	
24	M	42	39	PMRI	2.2	C	2	N	Y	I	100	43	10.8	0	0	

M, man; *W*, woman; *FU*, follow-up; *PMRI*, posteromedial rotational injury; *C*, comminuted; *Non-C*, non-comminuted; Plate type: *1*, sharp prongs; *2*, screws; *RHF*, radial head fracture; *MCL*, medial collateral ligament; *LCL*, lateral ulnar collateral ligament; *MEPS*, Mayo Elbow Performance Score; *OES*, Oxford Elbow Score; *DASH*, Disabilities of the Arm, Shoulder, and Hand; *Y*, yes; *N*, no; *HO*, heterotopic ossification; *OA*, osteoarthritis

seven cases, fractures occurred as part of a fall while skating in three cases. No open fractures were included.

Injury characteristics

According to the O'Driscoll classification, 11 cases were classified as subtype 2 (45.8%) and 13 cases as subtype 3 (54.2%) fractures; there were 17 comminuted fractures. Main injury mechanism was a posteromedial varus mechanism ($n = 13$), followed by terrible triad lesions and posterior dislocation (each $n = 4$). In one case, injury was associated with bony avulsion of the triceps muscle and, in two cases, a concomitant injury to the ipsilateral extremity (triquetral bone, dorsoradial distal humerus) was found.

A radial head fracture was evident in eight cases, of which five required additional surgery.

Eleven patients had solitary injuries to the LCL, five patients to the MCL, and four patients had a combined ligamentous lesion. Because of a significant elbow instability, LCL refixation was performed in 11 cases, whereas all MCL injuries showed a humeral detachment that could easily be fixed surgically by the medial approach. MCL injury was found more frequently ($n = 5$) in subtype 2 fractures, although this association did not reach statistical significance ($p = 0.208$).

Post-operative follow-up

All patients were available for a follow-up assessment after an average follow-up of 3.7 years (range, 12–86 months). In all cases, post-operative radiographic follow-up showed a concentric, anatomic restoration and no objective signs of instability. During the follow-up period, a complete bony union was achieved in all patients.

In seven patients, heterotopic ossification was apparent on the latest follow-up radiographs and was graded as type I osteoarthritic ossifications, but no statistical correlation could be drawn between their occurrence and the functional outcome.

According to the Broberg and Morrey radiographic classification system, three patients (12.5%) showed signs of post-traumatic osteoarthritis, of which two were classified as grade I and one as grade II.

The range of motion post-operatively showed a mean flexion of 125° (range, 90–140°) and a mean extension deficit of 7° (range, 0–30°) was detected. These results were significantly different compared with the unaffected side ($p < 0.001$). However, no statistical difference was found between the pronation-supination movements. In two cases, a grade I valgus instability was evident, but no varus or posterolateral instability was detected.

Post-operative pain evaluation and joint functional outcome

At the time of post-operative follow-up evaluation, the majority of patients reported an average pain level < 1 on VAS, with two patients who had a VAS pain score > 2. The mean MEPS was 98 (range, 85–100), with 21 patients achieving excellent results and three patients achieving good results. The mean OES was 43 (range, 31–48), and the mean DASH score was 7 (range, 0–23).

When the mechanism of patient trauma was considered, there were no significant differences in outcome (MEPS, OES, DASH) between posterior dislocation, posteromedial rotational injury (PMRI), and trans-olecranon fracture ($p = 0.385$). Also, neither the subtype of AMFF of the coronoid (subtype 2 or 3) nor the type of comminution was associated with significantly impaired functional outcome. However, superior results were found when coronoid fixation was the only surgical procedure ($n = 10$, $p = 0.040$), while an injury to the collateral ligament complex (LCL and/or MCL) had no significant impact on the functional outcome (Table 2).

Post-operative complications

None of the patients in this study required revision surgery due to post-operative loss of reduction, non-union, or implant-related complications.

However, in one case, post-operative ulnar nerve dysesthesia occurred, which fully resolved during the first three months. Because of persisting motion deficits (arc of motion < 90° in flexion-extension) in five patients, arthrolysis and implant removal were performed post-operatively after an average of 14 months, significantly improving the elbow range of motion ($p < 0.001$). At the time of the final follow-up assessment, 90% of patients had regained their pre-trauma levels of physical activity.

Table 2 Influence of different variables on the functional outcome following treatment of anteromedial facet fracture (AMFF) of the coronoid

	DASH *p* value	OES
Injury mechanism	0.159	0.363
Fracture type (2–2/3)	0.134	0.060
Comminution	0.787	0.522
Radial head fracture	0.555	0.543
LCL lesion	0.767	0.126
MCL lesion	0.226	0.674
Osteoarthritis	0.103	0.168

OES, Oxford Elbow Score; *DASH*, Disabilities of the Arm, Shoulder, and Hand; *LCL*, lateral ulnar collateral ligament; *MCL*, medial collateral ligament

Discussion

Anatomical reduction with stable internal fixation and early mobilization following fractures involving the anteromedial facet of the coronoid is important to prevent persistent elbow instability and to reduce the risk of early-onset traumatic osteoarthritis and elbow stiffness that results in improved functional outcomes [24, 30–32].

In our study, we could show that anatomically pre-formed coronoid plates were an effective option for the surgical treatment of AMFF of the coronoid, as all fractures healed and no redislocation or higher grades of osteoarthritis were detected. Furthermore, post-operative joint function was excellent as revealed by the mean scores of MEPS (98), OES (43), and DASH (7).

Additionally, we found that injuries to the MCL complex in the context of AMFF might be more frequent than reported in the current literature as we identified a relatively high rate of MCL complex injuries (33%) in our study. In our opinion, a possible reason for this might be that AMFF of the coronoid may not only be caused by varus force but also by rotational force, as found in the eight posterior dislocations.

However, when addressed sufficiently, good outcomes can be achieved.

Because the surgical anatomy of AMFF of the coronoid has been described only in a few studies, the optimal treatment protocol and technique remain to be identified [9, 11, 12, 16, 33–35]. Based on previous studies, the surgical guidelines for the management of AMFF may depend on the size of the fracture fragments and the extent of associated ligamentous lesions, recommending LCL repair alone when the fragment is < 5 mm and not easy to fix, whereas larger fracture fragments (subtypes 2 and 3) should be fixed in addition to LCL repair to prevent elbow instability [36].

Currently, there are several techniques of fixation for AMFF of the coronoid with no significant advantage for one over the other. Small anteromedial facet fractures may be best repaired with suture fixation, either alone or accompanied with screws [21, 37, 38]. However, severe comminution and multiple small fragments cannot be fixed by the suture, K-wire, or screw techniques, and in these cases, buttress plating is believed to be the biomechanically optimal fixation method [11–13, 39, 40].

However, there are only a few studies available in the current literature regarding the outcomes of plate osteosynthesis of the coronoid, especially in the context of AMFF of the coronoid [12, 38]. Lee et al. reported the results of 15 patients with the Reagan–Morrey type II or type III coronoid process fractures, including 12 subtype 2 or 3 fractures, treated with plate fixation and ligament repair [12]. While most of the patients showed good results after a mean follow-up of 14 months (mean arc of flexion-extension was 116° and mean MEPS was 88 points.), less favorable outcomes were seen in patients with post-traumatic osteoarthritis, and comminuted fractures or additional injuries to the LCL or radial head fractures (mean MEPS, 78.0 vs. 93.8).

However, these findings were not supported by our study. Although a comminuted fracture was present in 17 out of 24 patients, a stable reconstruction of the coronoid was achieved in all cases, and neither post-traumatic osteoarthritis nor LCL injuries had any significant influence on the functional outcome (Table 2).

Additionally, the use of pre-formed plating devices in the context of AMFF might be associated with a favourable outcome, as the functional scores in our study were slightly superior to those reported by Park et al. [11], who used with a 2.4 titanium handmade modified miniplate (Synthes, Inc., West Chester, PA, USA) as a buttress (average MEPS, 89). This may be due to the fact that these plates contour easily around the coronoid process and the specific screw system used provides additional stability to the reconstructed coronoid bone, even in comminuted fracture patterns. To what extent, a preoperative 3D-guided model may have helped to personalize the pre-operative plan and choice of implant could not be determined, although this technique has been associated with reduced time of surgery, intra-operative blood loss, and surgical risks in complex elbow fractures [41].

Ultimately, the findings of the present study support that, depending on the fracture location and size, the choice of the surgical approach is crucial.

While some authors advocate an anterior approach to the coronoid [42, 43], we used a medial flexor split approach to the coronoid in the present study, which is favoured by the unique shape of the plates. Hereby, even fractures involving the anterior parts of the coronoid could be sufficiently treated by either the sharp prongs or the additional screws of the plates. Also, the use of both plates minimized soft tissue stripping of the fracture fragment because of the small size of the implant and its design (low-profile). However, five patients required additional surgery within the first 2 years, mainly because of persisting elbow motion deficits. In our opinion, this could be attributed to the number of patients with complex mechanisms of injury included in the study (trans-olecranon dislocation-fracture, and "terrible triads"), as this has previously been reported to be an important risk factor for the development of post-traumatic elbow stiffness [44]. Although these complications are typically very difficult to treat, some authors have shown promising results when using a standardized treatment algorithm, including a complete release and an aggressive protocol in restoring stability of the elbow [45].

This study had several limitations, mainly due to its retrospective nature and the lack of a control group. However, these fractures are so rare and different from each other in relation to concomitant injuries like ligament ruptures, radial head fractures, and others that it would be impossible to match all cases at the same severity. Furthermore, the follow-up period was relatively short, which meant that the development of late complications, such as late-onset post-traumatic osteoarthritis or implant failure, could not be detected. However, in the current literature, a follow-up of two years is seen to be sufficient in terms of fracture healing, stability, range of movement, and early surgical complications in fracture pattern and treatment studies.

Nevertheless, this study represents the largest cohort of an infrequently described and even more difficult to treat lesion in the current literature, leading to good outcomes with low complications when using anatomically pre-formed buttress plates in the surgical treatment, even in complex fracture-dislocations.

Conclusions

AMFF of the coronoid are usually associated with injuries to the ligamentous complex. While injuries to the lateral collateral ligament (LCL) are recognized to be common associations with this type of fracture, injuries to the medial collateral ligament (MCL) are now recognized to be more common than previously realized. Stable fixation with the precise restoration of the joint congruity and careful restoration of all injured structures, even in comminuted fractures, are of the utmost importance and could be achieved using anatomically pre-formed coronoid plates, leading to excellent functional outcomes and limited development of post-traumatic osteoarthritis. However, one in five patients underwent a second operation for stiffness and plate removal. Future randomized controlled, comparative studies should be designed to evaluate the possible differences between fixation methods in patients with AMFF of the coronoid.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

The manuscript has been read and approved by all authors.

Each author believes that the manuscript represents honest work.

Conflict of interest The authors declare that they have no conflict of interest.

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No prior or duplicate submission or publication and no presentation of the study as an abstract at a professional meeting have been made elsewhere.