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Functional and radiographic outcomes after surgical management of complex proximal ulna fractures: a retrospective case series

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ABSTRACT

Background: Complex proximal ulna fractures (including comminuted olecranon fractures and fracture-dislocations of the elbow) pose challenging management due to concomitant injuries to key stabilizers (radial head, coronoid process, and collateral ligaments). This study evaluates functional and radiographic outcomes following surgical treatment and explores the prognostic value of associated injuries, age stratification, and a new coronoid-centric classification system.

Methods: We retrospectively reviewed 43 patients with complex proximal ulna fractures treated between 2019 and 2024, with a minimum of 12 months of follow-up (mean, 28 months). Fractures were categorized as complex olecranon (32.6%), transolecranon (16.3%), Monteggia (4.6%), or Monteggia-like (46.5%). We also applied the Mayo Clinic's coronoid-centric classification of proximal trans-ulnar fracture-dislocations, classifying cases as transolecranon (type I), Monteggia variant (type II), or transulnar basal coronoid (type III) fractures. According to this coronoid-centric classification, we obtained 11 transolecranon cases, 8 Monteggia variant, and 10 transulnar basal coronoid fractures. Associated injuries included radial head fractures in 56% (58.3% Mason IV) and coronoid fractures in 44.2%. Functional outcomes were assessed via range of motion, Mayo Elbow Performance Index, and Quick Disabilities of the Arm, Shoulder, and Hand. Subgroup analysis by age (≤65 vs. >65 years) was performed. Radiographs were reviewed for arthrosis, subluxation/dislocation, and heterotopic ossification. Complications were recorded.

Results: Mean age was 68 years. Mayo Elbow Performance Index and Quick Disabilities of the Arm, Shoulder, and Hand scores averaged 100 (85-100) and 6.8 (2.3-22.7), respectively. Mean range of motion was flexion 129.6°±9°, extension −21.7°±11°, pronation 90° (40°-90°), and supination 80° (45°-90°). Complications occurred in 14% of cases, including ulnar neurapraxia, nonunion, and hardware intolerance.

The Ethics Committee for Clinical Research (CEIC) from Clínico San Carlos Hospital approved this study (Internal code: 21/008-E).

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Patients with coronoid and/or radial head fractures had significantly worse outcomes. Worse results were also observed in patients aged ≤65 years ($P = .008$). Radiographic arthrosis occurred in 37% of cases, mainly grades 2 or 3.

Conclusions: Despite the complexity of these injuries, outcomes were generally favorable with a low complication rate. However, the presence of associated injuries to elbow stabilizers and transulnar basal coronoid fracture patterns per the Mayo classification was linked to poorer outcomes and higher arthrosis rates. Older age correlated with better functional recovery.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Proximal ulna; transolecranon fracture; Monteggia fracture; complex; elbow instability; coronoid fracture

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Proximal ulna fractures represent a broad spectrum of injuries that can range from simple olecranon fractures to complex fracture-dislocations involving critical stabilizing structures of the elbow. These include the radial head, coronoid process, and soft tissue attachments such as the lateral ulnar collateral ligament and the anterior band of the medial collateral ligament. Damage to these stabilizers significantly affects elbow biomechanics, often resulting in persistent instability or poor functional outcomes if not properly addressed.[41]

Traditional classification systems, such as those by Bado and Jupiter for Monteggia and Monteggia-like injuries, have been valuable for initial fracture description but have limited prognostic value, particularly in complex fracture-dislocations.[1,12,35,40,41] Similarly, transolecranon fracture-dislocations are often misclassified as simple olecranon fractures, leading to suboptimal surgical strategies.[13,16,35,44] In response to these limitations, a novel coronoid-centric classification system was introduced by the Mayo Clinic,[5] categorizing proximal transulnar fracture-dislocations into transolecranon, Monteggia variant, and transulnar basal coronoid fracture types. This system shifts focus toward the location and integrity of the coronoid and its associated stabilizing structures, offering improved interobserver reliability and potential prognostic value.

While several small case series[9,13,17,19,20,24,25,28-30,34,38,42] have evaluated the outcomes of complex proximal ulna fractures, few have incorporated this updated classification or examined the influence of patient-specific factors such as age on recovery. The purpose of this study was to evaluate the clinical and radiographic outcomes of surgically treated complex proximal ulna fractures, analyze complications, and assess prognostic variables including fracture subtype using the Mayo classification, concomitant injuries to elbow stabilizers, and patient age.

Materials and methods

Study design

This is a retrospective series of 43 patients conducted at a single tertiary referral center following institutional review board approval (C.I: 20/774-O_P). From 2019 to 2024, 104 patients with proximal ulna fractures underwent surgical treatment. Inclusion criteria were adult patients with complex proximal ulna fractures, defined as comminuted olecranon fractures (Mayo IIB), transolecranon fracture-dislocations (Mayo III), Monteggia or Monteggia-like injuries who underwent open reduction and internal fixation, and had at least 12 months of follow-up. Exclusion criteria were skeletally immature patients, prior elbow surgery, associated upper limb fractures outside the elbow, terrible triads or posteromedial fracture-dislocations, follow-up in another center, or incomplete follow-up.

A retrospective evaluation of collected medical and radiographic data from our institution's fracture database identified a cohort of 48 patients who had sustained a complex ulna fracture treated with open reduction and internal fixation, with a minimum follow-up of 12 months. Of these, 5 patients were excluded from the study: 2 died from causes unrelated to surgery and 3 were lost to final follow-up. The resulting study population consisted of 43 patients (a flowchart of the study is presented in Figure 1). These patients were contacted by telephone and invited to return for long-term functional and radiographic evaluation, which was conducted by 2 independent observers not involved in the original surgical treatment. The mean follow-up duration was 28 months (range, 12-44 months).

Surgical technique

All surgeries were performed using a posterior approach by at least 2 of the 3 senior surgeons with the patient in lateral decubitus position without tourniquet. The ulnar nerve was usually not identified, as this structure does not interfere with the surgical approach unless an anteromedial fragment from the coronoid process is present. In those cases, with involvement of the radial head and large and comminuted coronoid process, if there was no important displacement of the proximal ulnar fracture, full-thickness skin flaps were developed, and the injury was addressed through the lateral (Kocher approach) and medial interval (through the cubital tunnel floor and elevating the flexor-pronator muscle off the medial cortex of the proximal ulna). If there was important displacement of the proximal ulna with flexion of the fragment, it was preferred to address the radial head fracture as well as the coronoid fracture itself ‘through’ the ulnar fracture via the dorsal approach. Depending on the type of injury, the radial head was treated by fragment excision (if it was a partial articular fracture with less than 1/3 involvement of the radial head), fixation (Acutrak Headless Compression Screw System; Acumed, Hillsboro, OR, USA), or radial head arthroplasty (in cases of severe comminuted radial head fractures or elbow instability) (Ascension MRH–MedcomTech or Radial Head

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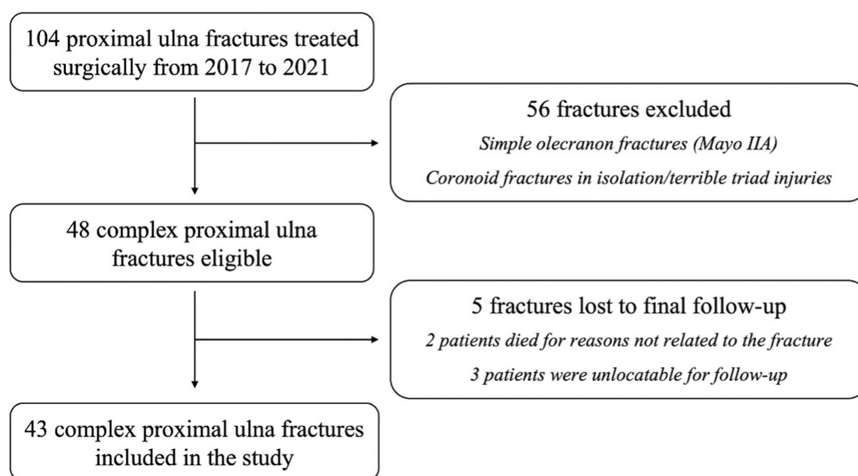

Figure 1 – Study flowchart.

Arthroplasty; DePuy Synthes, Raynham, MA, USA). Coronoid fracture was surgically fixed in most cases using variable angle screws from posterior to anterior through the dorsal plate, and in a few cases, it was fixed with an additional screw from the plate. None of the coronoid fractures required separate coronoid plate augmentation. An anatomically precontoured olecranon plate (LCP-VA Olecranon plate 2.7/3.5 DePuy Synthes or Elbow Plating System 'Olecranon Plate'–Acumed) were the implants of choice (Fig. 2).

Ligamentous instability was not typically addressed through direct soft tissue repair. Instead, in cases of complex proximal ulna fractures involving the anatomical insertion sites of the elbow's stabilizing ligaments—such as the supinator crest (for the lateral ulnar collateral ligament) or the sublime tubercle (for the ulnar collateral ligament)—stability was restored through anatomical fixation of these bony fragments. By addressing the bone–ligament complexes through osteosynthesis, the functional integrity of the stabilizers was indirectly reconstructed. Postoperatively, the elbow was rehabilitated in a position close to the torso to minimize stress on the repaired structures and allow biological healing of the ligament insertions.

Postoperatively, the elbow was placed in a plaster cast at 90° of flexion for about 2 weeks and then active and active-assisted exercises were started, allowing early motion of the elbow. Maximum weight-bearing and return to sports were allowed 3 to 6 months after surgery. No patient received postoperative heterotopic ossification prophylaxis. In cases with ligamentous repair, all motion was performed with the arm by the side to avoid any varus stress on the fixation.

Functional evaluation

Functional outcomes were assessed using the Mayo Elbow Performance Index (MEPI),[22] Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) scale,[15,18] and visual analog scale. A clinically meaningful difference for the QuickDASH score ranges from 5.3 to 11.7 points[35] for the Mayo Elbow Performance Score, a definitive minimal clinically important difference has not been validated in the literature for complex fractures of the proximal ulna[36]; however, some studies suggest that a change of approximately 10 points may be considered clinically relevant in certain elbow procedures.[23] Range of motion (ROM) measurements were obtained with a hand-held goniometer.

Radiographic assessment

Radiographic assessment included preoperative classification of the injury through plain radiographs and computed tomography scans in all cases (Bado and Jupiter classifications for Monteggia and Monteggia-like fractures, Mason classification for radial head fractures, and O'Driscoll classification for coronoid fractures and more recently, coronoid-centric classification from the Mayo clinic for complex ulna fractures) and the most recent anteroposterior and lateral radiographs of the involved elbow to assess evidence of fracture union, loss of fracture reduction, subluxation, heterotopic ossification classified by the Brooker system applied to the elbow,[14] and post-traumatic osteoarthritis according to the Broberg and Morrey classification system.[8]

This evaluation was performed by 2 independent orthopedic surgeon reviewers who were not involved in the management of the patients.

Statistical analysis

Quantitative variables were presented as mean and standard deviations and analyzed using Student's *t*-test and analysis of variance test; if the data were non-normal (as confirmed with the Shapiro-Wilk test), the median and interquartile range were reported, and a Wilcoxon test was used to perform the analysis. Correlation between fracture type and functional score were analyzed with the Kruskal-Wallis test and correlation between fracture type and reintervention rate with the Chi-square test. To account for the risk of false positives due to multiple comparisons, we applied the Benjamini-Hochberg correction to control the false discovery rate. Only P values that remained below .05 after adjustment were considered statistically significant. A P value $< .05$ was considered

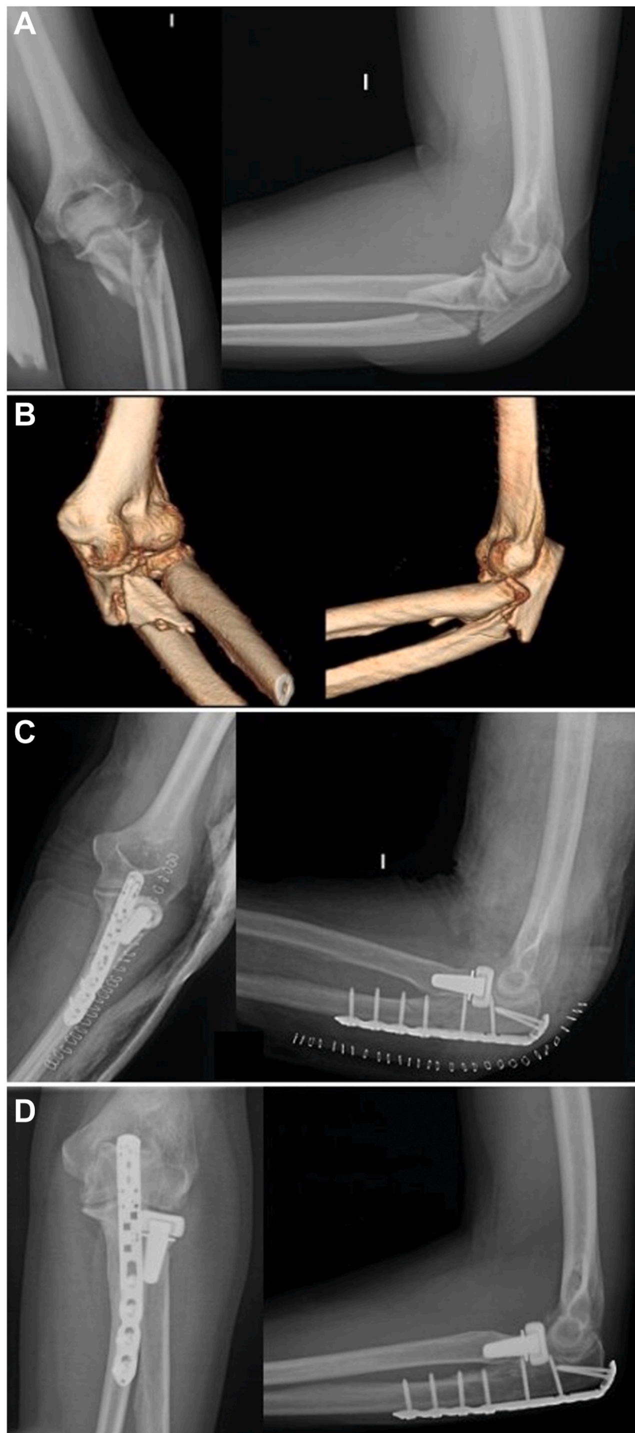

Figure 2 – Radiographic assessment of patients. **(A)** Initial plain radiographs upon arrival at emergency department. **(B)** CT scan requested to characterize the injury. In this case, a Monteggia-like injury is presented. **(C)** Immediate postoperative plain radiographic control. **(D)** Plain radiographs obtained at final follow-up. *CT*, computed tomography.

Table I – Demographic, epidemiological, and fracture pattern data

Variable	Data
Gender, n (%)	
Male	15 (35)
Female	28 (65)
Age, mean (range)	68 yr (19-83)
Follow-up, mean (range)	28 mo (16-44)
Osteoporosis, n (%)	
Yes	6 (14)
No	37 (86)
Dominant arm injury, n (%)	
Yes	24 (55.8)
No	19 (44.2)
Mechanism of injury, n (%)	
Low energy (fall from own height)	37 (86)
High energy	6 (14)
Traffic accident	2 (4.7)
Other	4 (9.3)
Fracture pattern, n (%)	
Complex olecranon fracture	14 (32.5)
Transolecranon fracture-dislocation	7 (16.3)
Monteggia fracture-dislocation	2 (4.7)
Monteggia-like injury	20 (46.5)
R-H dislocation	13 (30.2)
No R-H dislocation	7 (16.3)
Coronoid-centric classification of trans-ulnar fracture-dislocation, n (%)	
Transolecranon	11 (37.9)
Monteggia variant	8 (27.6)
Trans-ulnar basal coronoid	10 (34.5)

R-H, radio-humeral.

statistically significant. Statistical analysis was performed with IBM SPSS software (version 22; IBM, Armonk, NY, USA).

Results

Demographical and epidemiological data

Forty-three patients were included in the study: 28 females (65%) and 15 males (35%), with a mean age of 68 years (range, 58-76 years). Of these, 56% were aged more than 65 years. The most common injury mechanism was a fall from standing height (86%).

According to ulna fracture classifications, the most frequent types were complex olecranon fractures (14 patients, 32.5%) and Monteggia-like fractures (20 patients, 46.5%). A total of 29 patients (67.4%) had damage to at least one osseous elbow-stabilizing structure. The most common associated injury to elbow stabilizers was a radial head fracture, affecting 24 patients (55.8%). Mason type IV was the most frequent subtype (14 patients, 32.6%). Coronoid process fractures were identified in 19 patients (44.2%), and in 13 cases (30.2%), the fracture pattern involved the sublime tubercle. Combined

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Table II – Surgical data and associated injuries to elbow bony stabilizers

Variable	Data
Approach, n (%)	
Posterior	43 (100)
Time to surgery, d ± SD	3.46 ± 1.42
Hospital stay, d ± SD	1.93 ± 1.24
Radial head injury, n (%)	
Type of fracture, n (%)	24 (55.8)
I	2 (4.7)
II	4 (9.3)
III	4 (9.3)
IV	14 (32.5)
Surgical treatment, n (%)	
Internal fixation	13 (54.2)
Arthroplasty	9 (37.5)
Fragment excision	2 (8.3)
Coronoid process injury, n (%)	
Type of fracture, n (%)	19 (44.2)
I	6 (14)
II	10 (23.2)
III	3 (7)
Sublime tubercle injury	13 (30.2)
Surgical treatment, n (%)	
Screw fixation	19 (100)
Crista supinatoris injury, n (%)	15 (34.9)

SD, standard deviation.

fractures of the radial head and coronoid process were observed in 11 patients (25.6%). Crista supinatoris involvement was identified in 15 cases (34.9%).

According to the coronoid-centric Mayo Clinic classification, 11 fractures (37.9%) were classified as type I or trans-olecranon fracture dislocation, 8 (27.6%) as type II or Monteggia variant, and 10 (34.5%) as type III or transulnar basal coronoid fractures.

There were only 4 open fractures (9.3%), of which 3 were classified as Gustilo type I and one as Gustilo type IIA. Nine patients (20.9%) presented with additional associated injuries. No vascular or neurological injuries were diagnosed at the time of fracture. Demographic and epidemiological data are summarized in Table I.

Surgical data

The mean time to surgery was 3.46 ± 1.42 days. Average hospital stay was 1.93 ± 1.24 days, including the day of surgery.

Radial head fractures were treated by arthroplasty in 9 cases (18.6%) and by internal fixation in 13 cases (54.2%). Excision was performed only in 2 cases (8.3%). Coronoid fractures were fixed with a screw through the proximal ulnar plate in all cases.

Table II summarizes the most frequent injury associated with ulna fracture according to the fracture pattern and the surgical treatment employed.

Functional outcomes

The functional results and active mobility at last follow-up are summarized in Table III.

At final follow-up, the mean elbow ROM was flexion 130° ± 9°, extension −20° ± 11°, pronation 90° (range: 40°-90°), and supination 80° (range: 45°-90°). Mean MEPI score was 100 (range: 85-100) and mean QuickDASH was 6.8 (range: 2-23). Functional ROM (flexion-extension arc ≥100°) was restored in 95.3% of patients, and 86% achieved a functional pronation-supination arc (at least 50°-50°).

According to the proximal ulna fracture pattern described in the conventional classification system, functional results were significantly better in patients with the simplest ulna fracture pattern, consisting of complex olecranon fractures, vs. the other complex patterns. When we analyzed the results based on the new coronoid centric classification, there were no significant differences regarding ROM, except for supination ($P = .006$). Nevertheless, by grouping coronoid fixed to the metaphysis or to the olecranon, statistically significant differences were found with respect to type III in terms of functional results ($P = .036$). No significant differences were found between injuries with and without radio-humeral joint dislocation (Table III).

Overall functional outcomes in patients with stabilizing element injuries of the elbow are detailed in Table III. Patients with associated radial head fracture (regardless of radial head fracture pattern according to Mason classification) or coronoid fracture had significantly lower functional results than patients without these associated fractures. Finally, patients with fracture involvement of the crista supinatoris and sublime tubercle had poorer outcomes in terms of supination ($P = .012$) and supination and extension ($P = .013$; $P = .04$), respectively (Table III).

When we analyzed functional results according to demographic data, the only variable that was significantly related to worse functional results was age. Patients aged less than 65 years had worse functional results in supination ($P = .008$) and extension ($P = .06$) than patients aged more than 65 years (Table IV).

Radiographic evaluation and complications

No implant failures were observed in our series. The mean time to radiographic union was 14 weeks (range, 7 to 19 weeks). Radiographs at follow-up examination showed the presence of anterior or lateral heterotopic ossification in 5 cases (11.6%), which was significantly associated with the presence of a coronoid fracture ($P = .035$), but showed no demographic correlation (age: $P = .62$; sex: $P = .47$). However, this did not translate into clinical significance (Table V). In 37 cases (86%), radiographic signs of degenerative changes were observed at a mean of 23.2 months from surgery and osteoarthritis signs being statically associated with the presence of associated radial head fractures ($P = .006$) and coronoid fracture ($P = .03$), although there were no functional differences between patients with and without degenerative changes (Table V).

Overall, our complication rate reached 16.3%, including 3 cases of ulnar neuropathy, 2 of which resolved spontaneously, while one was persistent, and 3 cases of fracture nonunion (one pure Monteggia fracture-dislocation, one Monteggia-like injury, and one transolecranon fracture dislocation) that required reintervention. One additional patient required

Table III – Clinical outcomes of patients with complex olecranon fractures: global, according to fracture pattern and to associated injuries

Group	Flexion (°)	P value → BH	Extension (°)	P value → BH	Pronation (°)	P value → BH	Supination (°)	P value → BH	MEPS	P value → BH	QuickDASH	P value → BH
Global	130 ± 9		−20 ± 11		90 ± 10		80 ± 20		100 ± 15		7 ± 18	
Type of fracture (pattern)												
COF	130 ± 10	**.03 → 0.120***	−20 ± 10	.24 → 0.474	90 ± 0	.23 → 0.474	90 ± 3	**.02 → 0.096***	100 ± 5	.03 → 0.120	4 ± 2	**.015 → 0.077***
Rest:	130 ± 13		−20 ± 14		90 ± 12		70 ± 20		85 ± 16		11 ± 20	
TOFD	129 ± 13	.47 → 0.627	−22 ± 14	.57 → 0.696	80 ± 6	.41 → 0.557	68 ± 13	.29 → 0.497	85 ± 10	.28 → 0.492	11 ± 3	.23 → 0.474
MFD	127 ± 8	.62 → 0.744	−24 ± 7	.77 → 0.853	85 ± 5	.66 → 0.766	80 ± 10	.55 → 0.683	80 ± 12	.39 → 0.540	9 ± 3	.35 → 0.514
MLI	130 ± 28	.28 → 0.492	−20 ± 28	.31 → 0.506	90 ± 0	.32 → 0.506	75 ± 20	.38 → 0.536	90 ± 15	.37 → 0.533	8 ± 2	.3 → 0.502
MLI + RHD	131 ± 11	.33 → 0.506	−19 ± 13	.14 → 0.373	85 ± 6	.24 → 0.474	70 ± 13	.22 → 0.474	80 ± 10	.2 → 0.474	11 ± 3	.12 → 0.346
Associated injury												
RH	128 ± 2	.09 → 0.273	−23 ± 2	.49 → 0.630	80 ± 5	**.013 → 0.072***	68 ± 13	**.0005 → 0.009**	88 ± 12	**.001 → 0.0144**	14 ± 6	**.0013 → 0.016**
Mason IV	129 ± 2	.79 → 0.862	−22 ± 2	.96 → 0.970	78 ± 6	**.034 → 0.128***	65 ± 12	**.005 → 0.045**	86 ± 13	**.003 → 0.031**	13 ± 5	**.009 → 0.065***
Mason I-III	129 ± 2	.64 → 0.755	−24 ± 3	.35 → 0.514	75 ± 10	.83 → 0.892	60 ± 12	.68 → 0.777	84 ± 14	.48 → 0.628	14 ± 5	.14 → 0.373
Coronoid process	131 ± 3	.27 → 0.492	−19 ± 4	**.03 → 0.120***	83 ± 5	**.008 → 0.064***	68 ± 13	**.0001 → 0.036**	88 ± 10	**.0002 → 0.0048**	9 ± 4	**.0001 → 0.0036**
Sublime tubercle	128 ± 2	.74 → 0.833	−26 ± 2	**.04 → 0.144***	78 ± 5	.33 → 0.506	60 ± 10	**.013 → 0.072***	80 ± 13	.25 → 0.474	16 ± 7	.25 → 0.474
Crista supinatoris	131 ± 4	.87 → 0.908	−23 ± 3	.86 → 0.908	85 ± 5	.55 → 0.083	65 ± 10	**.012 → 0.072***	88 ± 10	.24 → 0.474	12 ± 5	.15 → 0.386
Coronoid centric												
Ulnar metaphysis	130 ± 9.1	.97 → 0.970	−20 ± 12.7	.17 → 0.422	85/75-90	.89 → 0.915	80/40-90	.06 → 0.196	87.7/55-100	.091 → 0.273	18.6/0-29	.055 → 0.189
Olecranon	130 ± 5.3		−20 ± 9.4		90/80-90		75/40-90		85.6/55-100		17.1/0-36	
Neither	130 ± 10		−30 ± 10.6		90/50-90		50/30-80		83.5/55-100		24.1/2.3-65	

BH, Benjamini–Hochberg; *MEPS*, Mayo Elbow Performance Score; *QuickDASH*, Quick Disabilities of the Arm, Shoulder, and Hand; *COF*, complex olecranon fracture; *TOFD*, transolecranon fracture-dislocation; *MFD*, Monteggia fracture-dislocation; *MLI*, Monteggia-like injury; *RHD*, radio-humeral dislocation; *RH*, radial head; *CP*, coronoid process; *CS*, crista supinaris.

BH indicates *P* value correction according to the Benjamini-Hochberg procedure. Asterisks denote *P* values that lose statistical significance after BH correction.

Bold values indicate statistically significant differences ($P < .05$).

Table IV – Clinical outcomes of patients with complex olecranon fractures according to age

Group	Flexion (°)	P value → BH	Extension (°)	P value → BH	Pronation (°)	P value → BH	Supination (°)	P value → BH	MEPS	P value → BH	QuickDASH	P value → BH
Age												
≤65	130 ± 1.9	.21 → 0.336	−25 ± 2.3	.06 → 0.180	90 ± 10.27	.23 → 0.336	70 ± 12.55	**.008* → 0.048***	100 ± 15.90	.28 → 0.336	6.8 ± 19.96	.47 → 0.470
>65	130 ± 2		−20 ± 2.3		90 ± 10.02		90 ± 17.96		100 ± 12.90		4.5 ± 15.20	

BH, Benjamini–Hochberg; *MEPS*, Mayo Elbow Performance Score; *QuickDASH*, Quick Disabilities of the Arm, Shoulder, and Hand; *BH*, Benjamini–Hochberg.
BH indicates *P* value correction according to the Benjamini-Hochberg procedure. Asterisks denote *P* values that lose statistical significance after BH correction.
Bold values indicate statistically significant differences (*P* < .05).

Table V – Radiological outcomes of patients with complex olecranon fractures

Group	N (%)	Flexion (°)	P value → BH	Extension (°)	P value → BH	Pronation (°)	P value → BH	Supination (°)	P value → BH	MEPS	P value → BH	QuickDASH	P value → BH
Osteoarthritis (B-M)													
Grade 0	6 (14)	130 ± 3.8	.74 → 0.779	−20 ± 4.4	.74 → 0.779	90 ± 0	.22 → 0.550	90 ± 22.51	.22 → 0.550	100 ± 2.04	.06 → 0.28	4.5 ± 7.27	.5 → 0.765
Grade I	22 (51.1)	130 ± 1.5		−20 ± 1.8		90 ± 10.98		80 ± 20.06		95 ± 15.19		6.2 ± 18.88	
Grade II-III	17 (34.9)												
HO (H-G)													
None	29 (67.5)	130 ± 1.8	.38 → 0.691	−20 ± 1.9	.55 → 0.765	90 ± 3.53	.79 → 0.79	90 ± 8.43	.65 → 0.765	100 ± 8.76	.28 → 0.622	4.5 ± 13.25	.35 → 0.691
Grade I	8 (18.6)	130 ± 2.3		−25 ± 3.2		90 ± 8.21		80 ± 13.87		95 ± 14.31		6.8 ± 17.40	
Grade II-III	6 (13.9)												

Associated injury	Radial head (*P* value → BH)	Coronoid process (*P* value → BH)	Sublime tubercle (*P* value → BH)	Crista supinatoris (*P* value → BH)
Orteoarthritis	.006 → 0.120*	.03 → 0.223*	.61 → 0.765	.21 → 0.550
HO	.46 → 0.765	.035 → 0.223*	.07 → 0.280	.63 → 0.765

BH, Benjamini–Hochberg; *MEPS*, Mayo Elbow Performance Score; *QuickDASH*, Quick Disabilities of the Arm, Shoulder, and Hand; *B-M*, Broberg-Morrey; *HO*, heterotopic ossifications; *H-G*, Hastings-Graham.
BH indicates *P*-value correction according to the Benjamini-Hochberg procedure. Asterisks denote *P* values that lose statistical significance after BH correction.
Clinical repercussion and relationship with associated injuries.

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reintervention because of residual instability; our global reintervention rate was 9.3%. Five patients (11.6%) needed hardware removal due to intolerance. No infection cases were recorded.

Discussion

Proximal ulna fractures account for approximately 10% of all upper limb fractures and 21% of all proximal forearm fractures.[39] These injuries present a particular challenge when they involve disruption of the elbow's primary stabilizing structures, such as the radial head, coronoid process, and collateral ligament attachments. Historically, they have been underappreciated due to the misclassification of complex patterns and the under-recognition of associated injuries, resulting in a wide spectrum of surgical outcomes and a non-negligible complication rate.

Numerous classification systems—most notably those by Bado, Jupiter, and O'Driscoll—have attempted to categorize these injuries to improve both diagnosis and surgical planning.[4,6,10,12,21,26,31,35,43] However, these systems often fall short in predicting prognosis and guiding therapeutic decisions, particularly in multifragmentary patterns. Monteggia-like injuries and transolecranon fracture-dislocations remain among the most frequently misclassified subtypes due to overlapping morphological traits and inconsistent use of terminology.[2,32] The recent coronoid-centric classification developed by the Mayo Clinic[5] offers a novel approach by focusing on the location and integrity of the coronoid in relation to major fracture fragments.

The present study is one of the first to apply the Mayo classification systematically and correlate it with clinical outcomes. We observed that transulnar basal coronoid fractures (where the coronoid is completely detached) were significantly associated with worse ROM and functional scores, corroborating recent findings by Nieboer et al,[33] who reported this pattern as the most unstable and prone to complications and reoperations in a systematic review.

Importantly, the correlation between specific anatomic injuries and functional results was evident in our series. The presence of radial head fractures (particularly Mason IV), coronoid process fragmentation, or fractures involving the sublime tubercle or crista supinatoris were all linked to diminished supination, greater loss of extension, and lower MEPI and QuickDASH scores. These findings echo those of Melamed et al[30] and Athwal et al,[3] underscoring the need to identify and address injuries to stabilizing structures when reconstructing the elbow.

In this context, it is worth highlighting the evolving understanding of the biomechanical role of the radial head. While traditionally considered a secondary stabilizer of the elbow when capsuloligamentous structures remain intact, our findings and those of others suggest that its importance increases notably in the setting of associated ligamentous disruption or coronoid fractures. Under these conditions, the radial head may become a primary stabilizer against valgus and posterolateral rotatory forces, emphasizing the need for its preservation or appropriate replacement during surgical reconstruction.

An interesting observation in our cohort was the influence of age on functional recovery. Despite representing an older population (mean age 68 years), which is considerably above the mean age reported in other series analyzing similar injuries[3,9,13,17,19,20,24,25,27-30,34] typically ranging between 40 and 60 years, patients aged more than 65 years demonstrated better functional outcomes than their younger counterparts, particularly in supination and overall motion. This may reflect age-related differences in inflammation, pain perception, or functional demands. Similar findings have been noted in previous series, although they remain underdiscussed in the literature.[9,13,17,19,20,28,29,34]

In relation to radiographic midterm postoperative evaluation, we found a significant relationship between the development of osteoarthritis in complex proximal ulnar fracture and the presence of radial head and coronoid fracture. The involvement of the sublime tubercle and the coronoid in the fracture pattern were also related to a significantly higher presence of heterotopic calcifications. Foruria et al[11] described a heterotopic ossification rate of 37%, with a 20% rate of relevant interference with elbow motion, and more severe cases associated with transolecranon and Monteggia fracture-dislocations. In the present study, 32.6% of patients had heterotopic ossifications, most of them mild (18.6% grade I), with poor correlation with clinical outcome.

Our complication rate of 14% and reintervention rate of 9.3% are favorable compared to previously reported rates ranging from 18% to 55% in similar series.[3,7,20,25,27,30,37] The higher failure rates observed in other studies are often attributed to inadequate preoperative diagnosis where one or more associated injuries go unrecognized, poor fracture reduction, unstable osteosynthesis, or excessively prolonged immobilization.

In the present study, we specifically analyzed whether the presence of preoperative radio-capitellar dislocation influenced the incidence of complications or led to poorer functional outcomes, but no significant association was found.

Despite these findings, the present study has limitations. Its retrospective nature and modest sample size may reduce statistical power and limit generalizability. The heterogeneity in fracture patterns and treatment modalities also introduces confounding factors. Nonetheless, our integration of the Mayo coronoid-centric classification and age-stratified analysis provides valuable insights and supports its potential as a complementary tool to existing classification systems.

Future research should aim to validate these findings in larger, prospective multicenter cohorts and explore the development of an expanded classification system incorporating not only fracture morphology but also soft tissue involvement—such as ligamentous and capsular injuries—for improved prognostic accuracy and treatment planning.

Conclusion

This study demonstrates that surgical treatment of complex proximal ulna fractures yields generally favorable functional and radiographic outcomes. However, results are significantly influenced by specific injury patterns and patient age. In particular, fractures involving the radial head, coronoid

process, sublime tubercle, and crista supinatoris were associated with worse functional scores, reduced ROM (especially in supination and extension), and a higher prevalence of radiographic osteoarthritis. Notably, patients aged more than 65 years showed significantly better functional recovery than younger counterparts, suggesting a possible influence of age-related physiological and functional factors. The application of the coronoid-centric classification allowed for a more refined understanding of fracture morphology and its correlation with prognosis. Specifically, transulnar basal coronoid fractures were clearly associated with inferior outcomes.

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