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TRAUMA SURGERY

Coronoid tip fractures in terrible triad injuries can be safely treated without fixation

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Abstract

Introduction The optimal treatment of terrible triad injuries of the elbow (TTI) remains topic of ongoing discussion. The aim of this study was to determine whether different treatment strategies for coronoid tip fractures in terrible triad injuries influences the clinical and radiological results in a mid-term follow-up.

Methods A total of 62 patients with surgical treatment of a TTI including a coronoid tip fracture (37 women, 25 men; mean age, 51 years) were available for follow-up assessment after an average of 4.2 years (range 24–110 months). Thirteen patients had O'Driscoll 1.1 and 49 O'Driscoll 1.2 coronoid fractures, of which 26 were treated with and 36 without fixation. Range of motion, the Mayo Elbow Performance Score (MEPS), Oxford Elbow Score (OES), and Disabilities of the Arm, Shoulder and Hand (DASH) score as well as grip strength were evaluated. Radiographs were analyzed for all participants.

Results No significant benefit in outcome variables could be detected between patients, whose coronoid had been fixed, compared to patients without fixation of the coronoid. In the coronoid fixation group, patients had mean outcome scores of 81.5 ± SD 19.1 (range 35–100) for MEPS, 31.0 ± SD 12.5 (range 11–48) for OES and 27.7 ± SD 23 (range 0–61) for DASH score, while in the no-fixation group, mean MEPS was 90.8 ± SD 16.5 (range 40–100), mean OES was 39.0 ± SD 10.4 (range 16–48) and mean DASH score was 14.5 ± SD 19.9 (range 0–48). Mean range of motion was 116° ± SD 21° (range 85–140°) versus 124° ± SD 24° (range 80–150°) in extension-flexion and 158° ± SD 23° (range 70–180°) versus 165° ± SD 12° (range 85–180°) in pronation-supination. Overall complication rate was 43.5% and revision rate was 24.2%, with no significant differences between both groups. Suboptimal results were more frequently seen in patients who had degenerative or heterotopic changes on their latest radiograph.

Conclusions Sufficient elbow stability and good outcomes can be achieved in most patients with TTI and coronoid tip fractures. Although some bias in treatment allocation and group heterogeneity cannot be completely omitted, our analysis detected no significant benefit in outcome when the coronoid tip fracture has been fixed compared to patients with non-fixed coronoid tip. Therefore, we would suggest a no-fixation approach for coronoid tip fractures as primary treatment in TTI of the elbow.

Level of evidence Level III**,** retrospective comparative study.

Keywords Terrible triad · Elbow dislocation fracture · Coronoid · Tip fracture · O'Driscoll 1

Introduction

If both the radial head and the coronoid are involved in elbow dislocations, these lesions are referred as 'terrible triad injuries' (TTI) [1]. Due to the loss of the postero-lateral stabilisation of the lateral ulnar collateral ligament (LUCL), the valgus buttress of the radial head, and the anterior buttress of the coronoid, these injuries are prone to result in chronic instability, elbow stiffness and post-traumatic arthritis, if not treated adaequately [2–5].

In this context, the coronoid process plays a significant role in stabilizing the ulnohumeral joint, as it forms an anterior buttress that in combination with the radial head prevents the elbow joint from posterior dislocation. Due to the posterolateral trauma mechanics [6], most coronoid fractures in TTI are small transverse fractures of the coronoid tip [7, 8].

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Currently, there is a consensus that only selected patients with a TTI can be treated non-operatively [9–11], whilst the vast majority requires surgical treatment to achieve a stable elbow which permits early rehabilitation [12–14]. If surgery is performed, each of the individual bony and soft-tissue components of the injury should be addressed based on the most recent treatment suggestions [14–16], leading to satisfactory clinical outcomes [17–20].

However, the decision, if a concomitant coronoid tip fracture should be fixed, remains controversial [21]. While some authors recommend skillful neglect [10] or excision of the fragment [22, 23], others suggest that any associated coronoid fracture, regardless of fracture classification, should be fixed [15, 22, 24–26]. However, most of these studies lack adequate cohort sizes or comparison group as well as a proper classification system for coronoid tip fractures. While attempts to classify these fragments according to height as defined by Regan and Morrey [27] have been inconsistent and contentious [28], O'Driscoll et al. [29] suggested a classification of coronoid fractures according to fracture morphology and injury pattern. Based on their classification system, coronoid tip fractures are referred as O'Driscoll type 1, which are usually associated with elbow dislocation in the context of a TTI. Therefore, our primary objective was to evaluate clinical outcomes of patients with a O'Driscoll type 1 coronoid fracture in a large sample of terrible triad lesions at mid-term follow-up. The secondary objective was to determine, if there is a difference in functional and clinical outcome between a surgical or a non-operative approach.

Methods

Study population

This is a cohort analysis of a retrospective case series at a single level-I trauma center. After approval by the Regional Ethics Committee (FF92/2018), patients were selected by searching the clinic's patient management system (medico® by Cerner Health Services GmbH, Idstein, Germany) from 2010 to 2018 for all surgically treated terrible triad injuries with coronoid tip fracture, using the code S53.12 of the International Statistical Classification of Diseases and Related Health Problems, Tenth Edition (ICD-10). Of those, 62 adult patients with TTI and concomitant coronoid tip fracture who underwent surgery in our hospital within 14 days after injury and without previous elbow surgery or elbow joint-specific comorbidities could be included for final assessment [Fig. 1].

Fractures of the coronoid were classified by two independent investigators (AN, PH), specialized in the field of elbow surgery, according to the O'Driscoll classification system [29]. Only type 1 fractures (coronoid tip fracture) were included (subtype 1.1, ≤ 2 mm coronoid height, subtype 1.2, > 2 mm coronoid height). Fractures of the radial head were classified according to its displacement pattern equivalent to the Mason system [30]; Open fractures were graded by the Gustilo and Anderson system [31].

Operative technique

Standard surgical approach was through Kocher's interval, while in cases where the MCL had to be addressed, we used a combined approach. Structures were generally addressed in a deep to superficial manner (coronoid, radial head, LUCL). All Mason type I fractures were treated non-operatively. In reconstructable Mason type II and type III fractures, the radial head was fixed using mini-screws or low-profile locking plates. If unreconstructable, radial head arthroplasty (RHA) was performed ($n = 20$) (15 × MoPyc Bioprofile, Tornier, France; 5 × SBi rHead, Stryker, USA). Coronoid fractures were treated based on surgeons' preference either non-operatively ($n = 36$) or reduced by screws ($n = 11$), if amendable for direct fixation, or by non-absorbable sutures in transosseous or suture-anchor-based manner ($n = 15$) [Figs. 2 and 3], if too small or comminuted for direct fixation with screws. The lateral collateral ligaments were repaired using 3.5 mm suture anchors (Arthrex, Naples, USA) in all cases. Stability of the elbow was then tested with the hanging arm test under flouroscopy. If instability,

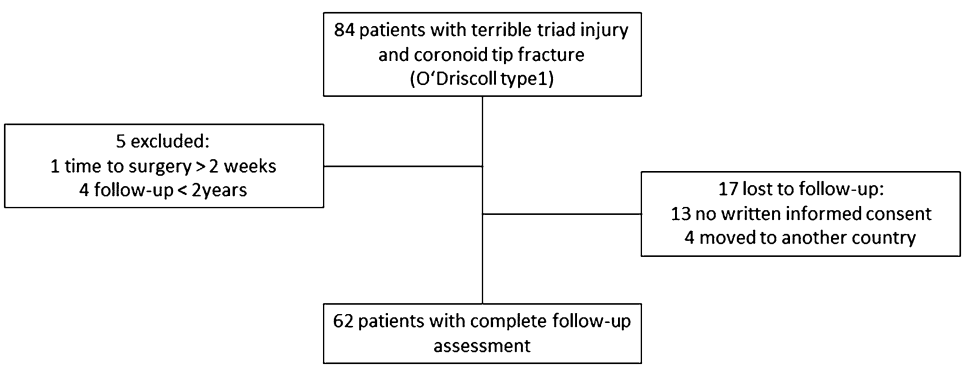

Fig. 1 Flowchart diagram of the process for patient inclusion in this study

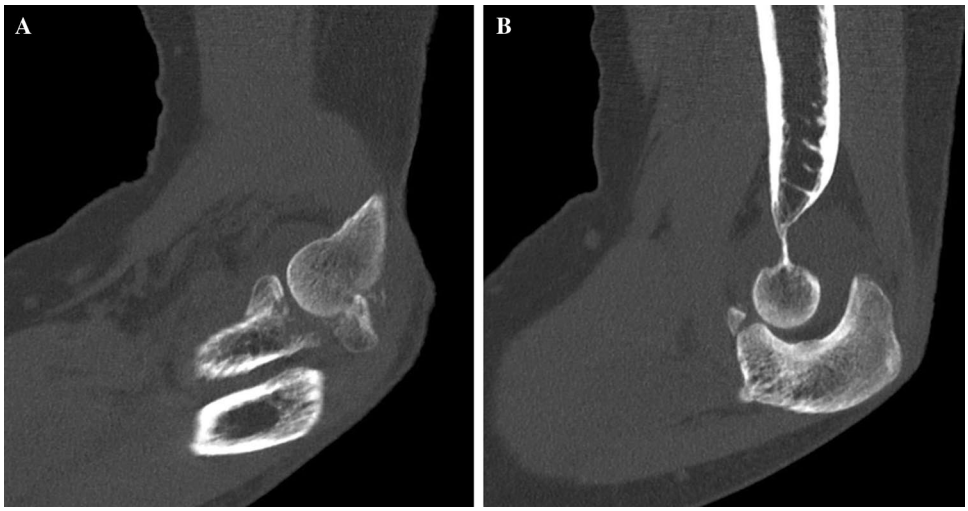

Fig. 2 Preoperative CT scans (**A**, **B**) of a 53-years-old female after a staircase fall, showing a terrible triad injury with a radial head fracture type Mason III equivalent and a coronoid tip fracture type O'Driscoll 1.2

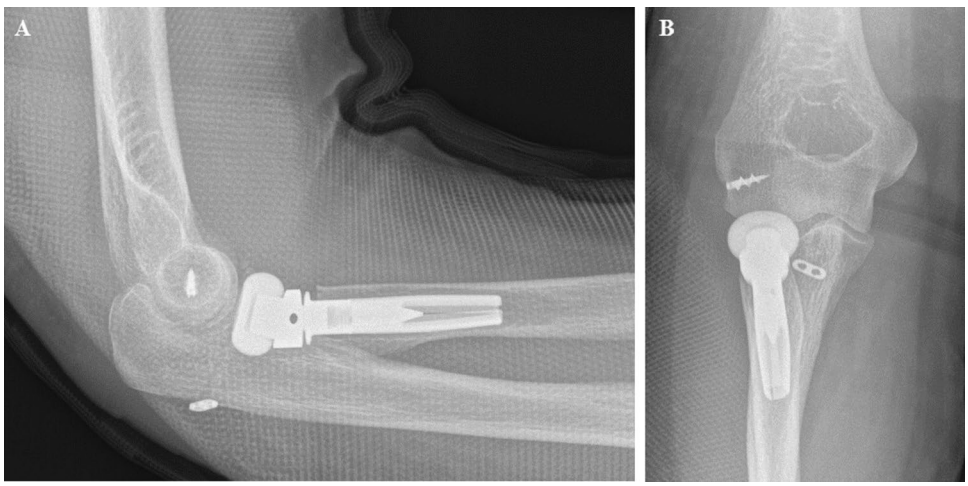

Fig. 3 Postoperative radiographs (ap, lateral) of the same patient as in Fig. 1. Radial head has been replaced by a modular monopolar model (MoPyc Bioprofile, Tornier, France) and the coronoid tip fracture has been reattached using a transosseous suture and button fixation at the posterior cortex of the ulna

defined as a non-concentric reduction of the ulnohumeral joint through a range of 20° to 130° of flexion–extension, persisted at this point, we proceeded to repair the medial collateral ligament (MCL) ($n = 27$). A hinged protective external fixator was applied in three patient due to excessive swelling after trauma, and was removed after 3 weeks.

Postoperatively, a hinged elbow brace in neutral forearm rotation was applied, from 20° of extension to 120° of flexion, for six weeks. Physiotherapy with active (without weight-bearing) and passive motion was indicated from the first postoperative day. All patients received oral nonsteroid anti-inflammatory medication for two weeks as an ossification prophylaxis.

Clinical and radiographic evaluation

After a minimum follow-up of 2 years, patients were invited for clinical evaluation by an independent investigator.

Range of motion of both elbow joints was tested using a standard goniometer and ligamentous stability was measured in maximum extension and at 30° of flexion. Elbow stiffness was rated according to the degree of the residual arc of motion (severe when the total arc was 60° or less, moderate when it was between 61 and 90°) [17]. Functional outcome was assessed using the Mayo Elbow Performance Score (MEPS) [32], Oxford Elbow Score (OES) [33], and the German Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire [34]. Posterolateral rotatory stability was evaluated using the posterolateral rotatory instability test and graded normal (0), mild (I), moderate (II), or severe (III) according to the grade of joint dislocation [35].

A Jamar dynamometer (Fabrication Enterprises Inc., White Plains, New York) was used to assess grip strength compared with the uninjured side, using a correction factor of 1.07 for the dominant over the nondominant hand [36].

Pain-level was rated using the visual analogue scale (VAS).

All available radiographs were evaluated by two independent investigators (AN, PH). Coronoid fracture height

was measured based on pre-operative CT scans using the technique described by Doornberg et al. [28]. Radiographic signs of osteoarthritis (OA) were rated according to Broberg and Morrey [37] and heterotopic ossifications (HO) were graded using the system of Hastings et al. [38]. Stability was assessed at final examination as a congruent joint on radiographs and absence of dislocation or subluxation events. Complications were defined as adverse events directly related to the chosen treatment, and were graded as 'major', if they required revision or if elbow stiffness (defined as range of motion < 60° in extension-flexion) persisted after 6 months. Revision was defined as any subsequent surgical intervention related to the index procedure.

Sample size calculation and statistical analysis

To determine the adequate sample size for group comparisons between the surgical treatment options of the coronoid tip (operative vs. non-operative), we used the OES as our primary outcome variable, which has a minimal clinically important difference of 8.2 for the elbow [39]. Consequently, a two-sided unpaired *t* test with an alpha-level of 0.05, a power of 80%, and an allocation ratio of 1, requires 26 patients in each group to detect an effect size of 0.8.

Statistical analysis was conducted using IBM SPSS statistics version 25 (IBM Germany GmbH, Ehningen, Germany). Fisher's exact test was used for determining statistical differences for categorical data such as stability, complication or reoperation rate, HO and OA. Mean values were compared using independent *t* tests for normally distributed variables and Mann–Whitney *U* tests for non-parametric variables, when applicable. If more than two groups were compared, either a one-way ANOVA or the Kruskal–Wallis test were performed. *P* values of < 0.05 were considered significant.

Results

Patient demographics are detailed in Table 1. The average follow-up was 4.2 years (range 24–110 months). At final follow-up, mean flexion–extension range of motion (ROM) was 121° (range 85°–150°) and mean pronation-supination ROM of the forearm was 162° (range 90°–180°), both differing significantly to the unaffected side ($P < 0.001$).

Average pain-level measured using the VAS was 1.5 (SD 2.1), although five patients had to rely on pain medication due to chronic elbow pain. At the final visit, mean MEPS was 86.9 (range 35–100), mean OES was 36.0 (range 11–48) and mean DASH score was 20 (range 0–61), with about 75% of patients reporting excellent or good results ($n = 46$). A mean grip strength of 88.7% (range 43–130%) was measured compared with the uninjured arm, with about half of patients regaining at least 90% of the uninjured side. Grade-I posterolateral, and mild valgus instability were detected in one and four cases, with no correlation between the occurrence of a valgus instability and the treatment of the coronoid or MCL-complex.

Table 1 Patients demographics

	Total ($N = 62$)
Demographics	
Age	50.6 years (range 18–82 years)
Female	37 (59.7%)
Male	25 (40.3%)
Trauma mechanism	
Fall/low-energy	55
Fall > 2 m/high energy	7
Fracture classification	
Radial head fracture	62 (100%)
Mason I	4 (6.5%)
Mason II	11 (17.7%)
Mason III	47 (75.8%)
Coronoid fracture	62 (100%)
O'Driscoll 1.1	13 (21.0%)
O'Driscoll 1.2	49 (79.0%)
Open fractures	1 (1.6%)
LCL repair	62 (100%)
MCL repair	27 (43.5%)

Impact of coronoid treatment

All fractures showed no involvement of the anteromedial facet, with all fractures affecting the tip and/or the anterolateral facet of the coronoid. Average coronoid fracture height was measured 5.4 mm (range 0.5–11.1 mm), ranging between 3 and 30 percent of complete coronoid height. While the (percentage) height of the coronoid fractures had no statistical influence on the final outcome ($P_{MEPS} = 0.482$; $P_{OES} = 0.323$), patients with a O'Driscoll subtype 1.2 fracture showed a greater impairment in function and range of motion than those with subtype 1.1 fracture [Table 2].

Considering the treatment applied to the coronoid, there were no statistical differences in demographics or concomitant treatment procedures between both groups, except for a higher rate of radial head arthroplasty in patients with surgically treated coronoid [Table 3].

Overall, no significant benefit in outcome variables was detected when the coronoid tip fracture has been fixed [Table 4], with the non-fixation group even showing significantly more favorable results without consideration of the group heterogenity. In order to minimize selection bias in both groups, stratification for radial head treatment

Table 2 Comparison of the different types of coronoid tip fractures with regard to functional and clinical outcomes (abbreviations in the main text)

	O'Driscoll 1.1	O'Driscoll 1.2	*P* value*
Number of patients	13	49	
Coronoid fixation	3	23	0.121
Arc of motion (Ext/Flex)	127° (SD 13°)	116° (SD 24°)	**0.029**†
Arc of motion (Pro/Sup)	170° (SD 7°)	160° (SD 19°)	0.061
MEPS	96.2 (SD 8.9)	84.5 (SD 19.1)	0.051
OES	40.8 (SD 7.7)	34.8 (SD 12.4)	0.160
DASH	10.0 (SD 12.8)	24.7 (SD 12.8)	0.158
Grip strength (to uninjured side)	96.0% (SD 18.7%)	86.9% (SD 22.4%)	0.524

P values of < 0.05 were considered significant in bold

*Mann–Whitney *U* test

†Significant

Table 3 Patient demographics for different coronoid fracture procedures (abbreviations in the text)

	Fixation ($n=26$)	No fixation ($n=36$)	*P* value
Age	52.1 years (range 20–82 years)	49.5 years (range 18–80 years)	$P=0.516$
Gender	12 male, 14 female	13 male, 23 female	
Follow-up (months)	46.1 (SD 28.3)	53.4 (SD 27.5)	$P=0.158$
Radial head fracture			
Mason 1	2 (7.7%)	2 (5.6%)	$P=0.735$
Mason 2	4 (15.4%)	7 (19.4%)	$P=0.680$
Mason 3	20 (76.1%)	27 (75.0%)	$P=0.861$
Radial head treatment	24 (92.3%)	35 (97.2%)	
Radial head arthroplasty	13 (50.0%)	7 (19.4%)	$\boldsymbol{P=0.011}$†
ORIF	11 (42.3%)	28 (77.8%)	$\boldsymbol{P=0.004}$†
Ligament treatment			
LCL repair	26 (100%)	36 (100%)	$P=1.000$
MCL repair	14 (53.8%)	13 (36.1%)	$P=0.165$
Complications	11 (42.3%)	16 (44.4%)	$P=0.867$
Reoperations	9 (34.6%)	9 (25%)	$P=0.410$

P values of < 0.05 were considered significant in bold

*Fisher's exact test

†Significant

also revealed better movement and function for an non-operative treatment of the coronoid, but no statistical differences was reached ($P_{MEPS}=0.112$) in all outcome variables.

Radiographic evaluation

Follow-up radiographs showed the development of HO in 16 cases (12, stage 1; 1, stage 2A; and 3, stage 2C ossification), with no significant reference to a certain treatment procedure of the coronoid (Fisher's exact, $P=0.177$). However, the occurrence of HO led to significantly worse range of motion and functional outcome parameters [Table 5].

Eighteen patients showed signs of OA on their latest radiographs independent of coronoid treatment procedure ($P=0.165$), including 12 with grade I and 6 grade II degenerative changes. Similar to HO, OA was also associated with significantly inferior outcome scores [Table 5].

Complications and reoperations

With all 62 patients included, the total incidence of major complications was 43.5% ($n=27$), with eighteen patients (24.2%) requiring at least one second surgical procedure during follow-up. These included three cases of postoperatively

Table 4 Comparison of the different treatment procedures for coronoid fractures with regard to functional and clinical outcomes (abbreviations in the main text)

	Fixation	No fixation	*P* value*
Number of patients	26	36	
Arc of motion (Ext/Flex)	116° (SD 21°)	124° (SD 24°)	0.203
Arc of motion (Pro/Sup)	158° (SD 23°)	165° (SD 12°)	0.168
MEPS	81.5 (SD 19.1)	90.8 (SD 16.5)	**0.014**†
OES	31.9 (SD 12.5)	39.0 (SD 10.4)	**0.015**†
DASH	27.7 (SD 23.8)	14.5 (SD 19.9)	**0.014**†
Grip strength (to uninjured side)	88.4% (SD 20.3%)	89.2% (SD 23.2%)	0.897

P values of < 0.05 were considered significant in bold

*Mann–Whitney *U* test

†Significant

persisting humeroulnar subluxation (two in the fixation and one in the no-fixation group), which were treated by revision surgery with an additional medial ligamentous repair in two and application of a hinged external fixator in one patient, who already had fixation of his coronoid during index procedure. In one patients, an early peri-implant infection was successfully treated by surgical revision. During follow-up, no secondary dislocation of the elbow occurred. The largest portion of complications was due to patients with ongoing severe joint stiffness ($n = 18$), of which seven patients underwent surgical arthrolysis during the first postoperative year. Additionally ulnar neurolysis due to persisting ulnar dysesthesia was necessary in three patients. Overall, no statistical difference in complication or revision rate could be detected between both treatment groups, although severe joint stiffness and subsequent arthrolysis was more frequently performed in the coronoid fixation group [Table 3].

Discussion

The treatment of TTI of the elbow is challenging and can lead to an unsatisfactory outcome. In this context, the optimal treatment of certain aspects of these injuries remain unclear. Surgical reconstruction aims to restore sufficient elbow stability to allow early mobilization within a stable arc of motion. While most authors agree that the radial head should be fixed or replaced [20, 40, 41], and the LUCL should be repaired to provide posterolateral stability [16, 42], the optimal treatment strategy for coronoid (tip) fractures remains topic of current discussion. We, therefore, present the results of the largest comparative study of these lesions yet published. Based on our findings, no benefits on clinical and functional outcome could be detected, if the coronoid tip fracture was surgically fixed. Furthermore no residual instability was evident in any patient at the latest follow-up visit. However, we detected a rather high complication (43.5%) and revision rate (24.2%) in our study cohort, independent of the coronoid tip treatment. While, these rates seem high compared to previous studies, it should be noted that our main complication (as well as main indication for revision) has been symptomatic elbow stiffness, which has not always been considered a "complication" in most other studies. However, as these conditions are usually very limiting for the patients, we think, this should also be seen as such, thus leading to a higher complication/revision rate in our cohort. As those injuries are regularly very severe and challenging, this only emphasizes the importance of an adequate treatment. Due to its eminent role for elbow stability, most coronoid fractures in TTI have historically been treated surgically [15, 43, 44].

Table 5 Outcomes of patients with heterotopic ossifications (HO) or osteoarthritis (OA) on their latest radiographs (abbreviations in the text)

	HO	No HO	*P* value*	OA	No OA	*P* value*
Number of patients	16	46		18	44	
Arc of motion (Ext/Flex)	100° (SD 27°)	128° (SD 17°)	**< 0.001**†	101° (SD 27°)	130° (SD 16°)	**< 0.001**†
Arc of motion (Pro/Sup)	149° (SD 27°)	166° (SD 10°)	**0.010**†	146° (SD 24°)	168° (SD 9°)	**< 0.001**†
MEPS	72.5 (SD 21.8)	92.0 (SD 13.6)	**< 0.001**†	73.6 (SD 22.3)	92.4 (SD 12.7)	**< 0.001**†
OES	27.5 (SD 11.7)	39.0 (SD 10.3)	**0.002**†	26.7 (SD 11.4)	39.8 (SD 9.7)	**< 0.001**†
DASH	36.5 (SD 22.1)	14.3 (SD 19.7)	**< 0.001**†	38.8 (SD 21.6)	17.9 (SD 21.6)	**< 0.001**†

P values of < 0.05 were considered significant in bold

*Mann–Whitney *U* test

†Significant

However, evolving scientific research and biomechanical analyses over the last decade have led to a better understanding of the complexity of elbow injuries and the importance of restoring stability through the coronoid [22, 23, 45].

Based on the kinematic analyses by Doornberg et al., the majority of coronoid fractures in TTI can be classified as small transverse (anterolateral) tip fractures (type 1 according to O'Driscoll) [8], rarely exceeding 30% of the coronoid height, which can be confirmed by the data of our study cohort. Due to the attachment of the anterior capsule many authors suggest repair of these lesions (and its capsular attachment) to sufficiently restore the anterior column of the elbow joint [4, 15, 25, 42, 46]. However, cadaver studies showed no impairment in elbow stability if less than 30% of the coronoid have been resected, as long as the MCL and radial head remain intact [22, 26, 45].

However, caution has to be exercised when attempting to transfer the results of biomechanical studies to the clinical setting, because the complexity of elbow injuries, coupled with in vivo motion, and the stresses across the human elbow, cannot be completely replicated in laboratory settings.

Antoni et al. [47] reported that reattaching the anterior capsule in terrible triad injuries did not improve the final clinical and radiographic outcomes, although radiographic evidence of humero-radial osteoarthritis was significantly more common in the absence of re-attachment. They concluded that elbow stability can be achieved without coronoid fixation if a coronoid process fracture does not involve anteromedial facet or the fracture is less than 50% of the coronoid height. These findings are in line with the conclusions drawn by our study, as no functional benefit could be detected when the coronoid was surgically repaired. Similar findings have also been reported by Papatheodorou et al. [10], who found very good functional outcome scores [mean Broberg and Morrey score of 90 (range 70–100) and an average DASH score of 14 (range 0–38)] without any residual instability in a series of 14 terrible triad injuries with Reagan-Morrey type I or II coronoid fractures, that were treated without fixation. Although this study lacks a comparison group, a higher number of cases and a more specific classification system, they suggested a non-operative treatment for these lesions barring intraoperative elbow stability can be achieved after reconstruction of a radial head fracture and the LCL complex. In the most recent study, Kim et al. [48] presented the outcomes of 24 patients, that were treated by a single surgeon with a standardized surgical protocol, including no reconstruction of coronoid (Reagan-Morrey) type I and II fractures. At the final follow-up, the mean MEPS and Quick-DASH score were 91.5 and 17.3, respectively, with no recurrent instability. Although no comparison group has been established, the authors conclude, that Reagan-Morrey type I and II coronoid fractures in terrible triad injuries do not need to be fixed if the radial head and ligamentous complex are completely reconstructed. Moreover, data of our study suggest even worse outcome scores and ROM, when the coronoid tip had been reconstructed (although not statistically significant). We suppose, that fixation of the coronoid tip (and its attachment of the anterior capsule) could lead to more "stiff" elbow postoperatively, which temporarily or permanently limits elbow function in the rehabilitation process, resulting in a greater loss of ROM in this group. Likewise, a higher rate of severe joint stiffness and surgical arthrolysis procedures were performed in the fixation group. However, in this context group, heterogeneity also has to be taken into consideration, as significantly more RHA had been implanted in the (coronoid) surgical intervention group, which was previously reported to be associated with a significantly inferior outcome in the context of a TTI [20, 49]. However, when stratified for radial head treatment, results between both treatment groups remained the comparable.

Although we detected no significant differences in injuries or treatment procedures to further structures around the elbow between each treatment group, the inferior outcomes following surgical treatment of the coronoid might also be related to a more severe injury mechanism. This might be evidenced by greater number of radial head arthroplasties, indicating a more severe (soft) tissue damage. Additionally, HO itself is a severe complication of elbow trauma that shows its highest prevalence in elbow dislocations [50, 51]. It frequently leads to functional impairment of the elbow, as also seen in our study population. Similarly, OA was frequently detected in our patients, and was associated with significantly inferior outcomes. However, both treatment groups showed no statistical difference in the occurrence of this disease, which is why we could not determine the extent to which treatment to the coronoid (occult microinstability) or other structures (radial head) or even the initial injury (occult cartilage lesions) affected the outcome.

Taking these aspects into consideration, treatment of the coronoid tip fractures seems to play a rather minor role for final outcome of TTI compared to the treatment of the radial head and ligamentous structures [49, 52–54], as long as a stable elbow joint has intraoperatively been achieved. Nevertheless, recognition of all coronoid lesions and structured treatment is mandatory to minimize complications like OA or HO following TTI.

This study has some limitations: patients were not randomized to any particular treatment method; thus, surgeon and selection bias may have affected the results. However, not only the surgeon, but also the severity of the injury itself might have influenced the choice for a certain treatment method, with surgical treatment of the coronoid more likely being performed in cases where the radial head had to be replaced, surrogating for a higher energy injury or a better surgical access. However, the study population represents,

by far, the largest comparative study on coronoid tip fractures in context of TTI in the current literature. Furthermore, no substantial group differences, such as age, sex distribution, or mean time from injury to operation could be detected, suggesting enrolment occurred without bias. Ultimately, the development of late complications, such as late onset post-traumatic arthritis could not be detected because of the mid-term design of this study. However, a review of the literature indicates that a follow-up of two years is considered sufficient for the assessment of fracture healing, stability, range of motion, and early surgical complications in fracture pattern and treatment studies.

Conclusion

Recognition of all associated injury patterns helps to provide optimal treatment strategies in terrible triad lesions of the elbow. This leads to sufficient elbow stability and good outcome scores in the majority of cases. While bias in treatment allocation and group heterogeneity cannot be completely omitted, our clinical and statistical analysis detected a beneficial effect of non-surgical treatment of O'Driscoll type 1 coronoid fractures on the midterm outcome, especially in terms of elbow function, ROM, incidence of arthrosis and postoperative complications, although it did not reach statistical significance. Therefore, future research including randomized-controlled trials is needed in order to improve treatment recommendations in these complex injuries.

Author contributions AK: conception and design, acquisition, examining patients, analysis and interpretation of data, writing the manuscript, statistical analysis, critically revising the article. AN: examining the patients, data analysis, reviewed submitted version of manuscript. sf: proofreading the manuscript, statistical analysis, data analysis. PH: proofreading the manuscript, data analysis, statistical analysis, data analysis. YG: proofreading the manuscript, conception and design, data analysis, administrative/technical/material support. RH: proofreading the manuscript, conception and design, data analysis, administrative/technical/material support.

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Data availability Due to the sensitive nature of the data in this study, survey respondents were assured raw data would remain confidential and would not be shared.

Declarations

Conflict of interest None of the authors, their immediate families, nor any research foundation with which they are affiliated, received any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical approval The study has been approved by the Ethical Committee of the Regional Medical board of Hessen, Germany (under study ID FF92/2018).

Consent to participate All investigations were conducted in conformity with the principles of good clinical practice and the ethical principles of research based on the 1964 Declaration of Helsinki, and informed consent for participation in the study was obtained.

References

1. Hotchkiss RN (1996) Fractures and dislocations of the elbow. In: Rockwood CA Jr, Green DP, Bucholz RW, Heckman JD (eds) Rockwood and Green's fractures, 4th edn. Lippincott-Raven, pp 929–1024
2. Josefsson PO, Gentz CF, Johnell O et al (1989) Dislocations of the elbow and intraarticular fractures. Clin Orthop Relat Res. https://doi.org/10.1097/00003086-198909000-00020
3. Kälicke T, Muhr G, Frangen TM (2007) Dislocation of the elbow with fractures of the coronoid process and radial head. Arch Orthop Trauma Surg 127:925–931. https://doi.org/10.1007/s00402-007-0424-6
4. Ring D, Jupiter JB, Zilberfarb J (2002) Posterior dislocation of the elbow with fractures of the radial head and coronoid. J Bone Jt Surg Am 84:547–551. https://doi.org/10.2106/00004623-200204000-00006
5. Broberg MA, Morrey BF (1987) Results of treatment of fracture-dislocations of the elbow. Clin Orthop Relat Res 216:109–119
6. O'Driscoll SW, Bell DF, Morrey BF (1991) Posterolateral rotatory instability of the elbow. J Bone Jt Surg 73:440–446. https://doi.org/10.2106/00004623-199173030-00015
7. Mellema JJ, Doornberg JN, Dyer GSM et al (2014) Distribution of coronoid fracture lines by specific patterns of traumatic elbow instability. J Hand Surg 39:2041–2046. https://doi.org/10.1016/j.jhsa.2014.06.123
8. Doornberg JN, Ring D (2006) Coronoid fracture patterns. J Hand Surg 31:45–52. https://doi.org/10.1016/j.jhsa.2005.08.014
9. Najd Mazhar F, Jafari D, Mirzaei A (2017) Evaluation of functional outcome after nonsurgical management of terrible triad injuries of the elbow. J Shoulder Elbow Surg 26:1342–1347. https://doi.org/10.1016/j.jse.2017.05.012
10. Papatheodorou LK, Rubright JH, Heim KA et al (2014) Terrible triad injuries of the elbow: does the coronoid always need to be fixed? Clin Orthop Relat Res 472:2084–2091. https://doi.org/10.1007/s11999-014-3471-7
11. Chan K, MacDermid JC, Faber KJ et al (2014) Can we treat select terrible triad injuries nonoperatively? Clin Orthop Relat Res 472:2092–2099. https://doi.org/10.1007/s11999-014-3518-9
12. Chen NC, Ring D (2015) Terrible triad injuries of the elbow. J Hand Surg 40:2297–2303. https://doi.org/10.1016/j.jhsa.2015.04.039
13. Chemama B, Bonnevialle N, Peter O et al (2010) Terrible triad injury of the elbow: how to improve outcomes? Orthop Traumatol Surg Res 96:147–154. https://doi.org/10.1016/j.rcot.2010.02.008
14. Liu G, Ma W, Li M et al (2018) Operative treatment of terrible triad of the elbow with a modified Pugh standard protocol: retrospective analysis of a prospective cohort. Medicine (Baltimore) 97:e0523. https://doi.org/10.1097/MD.0000000000010523
15. Pugh DMW, Wild LM, Schemitsch EH et al (2004) Standard surgical protocol to treat elbow dislocations with radial head and coronoid fractures. J Bone Jt Surg 86:1122–1130. https://doi.org/10.2106/00004623-200406000-00002

16. Rodriguez-Martin J, Pretell-Mazzini J, Andres-Esteban EM et al (2011) Outcomes after terrible triads of the elbow treated with the current surgical protocols. A review. Int Orthop 35:851–860. https://doi.org/10.1007/s00264-010-1024-6
17. Giannicola G, Calella P, Piccioli A et al (2015) Terrible triad of the elbow: is it still a troublesome injury? Injury 46:S68–S76. https://doi.org/10.1016/S0020-1383(15)30058-9
18. Jones ADR, Jordan RW (2017) Complex elbow dislocations and the "terrible triad" injury. Open Orthop J 11:1394–1404. https://doi.org/10.2174/1874325001711011394
19. Jiménez-Martín A, Contreras-Joya M, Navarro-Martínez S et al (2020) Resultados clínicos de la artroplastia radial en la tríada terrible de Hotchkiss, a propósito de 47 casos (Clinical results of radial arthroplasty in Hotchkiss' terrible triad, a case series of 47). Rev Esp Cir Ortop Traumatol 64:83–91. https://doi.org/10.1016/j.recot.2019.11.003
20. Klug A, Nagy A, Gramlich Y et al (2020) Surgical treatment of the radial head is crucial for the outcome in terrible triad injuries of the elbow. Bone Jt J 102-B:1620–1628. https://doi.org/10.1302/0301-620X.102B12.BJJ-2020-0762.R1
21. Chen H, Wu J, Zhao P et al (2020) Functional outcomes after treatments for different types of isolated ulnar coronoid fracture: a protocol for systematic review. Medicine (Baltimore) 99:e19830. https://doi.org/10.1097/MD.0000000000019830
22. Beingessner DM, Stacpoole RA, Dunning CE et al (2007) The effect of suture fixation of type I coronoid fractures on the kinematics and stability of the elbow with and without medial collateral ligament repair. J Shoulder Elbow Surg 16:213–217. https://doi.org/10.1016/j.jse.2006.06.015
23. Closkey RF, Goode JR, Kirschenbaum D et al (2000) The role of the coronoid process in elbow stability. A biomechanical analysis of axial loading. J Bone Jt Surg 82:1749–1753. https://doi.org/10.2106/00004623-200012000-00009
24. Cohen MS (2004) Fractures of the coronoid process. Hand Clin 20:443–453. https://doi.org/10.1016/j.hcl.2004.07.004
25. Garrigues GE, Wray WH, Lindenhovius ALC et al (2011) Fixation of the coronoid process in elbow fracture-dislocations. J Bone Jt Surg 93:1873–1881. https://doi.org/10.2106/JBJS.I.01673
26. Schneeberger AG, Sadowski MM, Jacob HAC (2004) Coronoid process and radial head as posterolateral rotatory stabilizers of the elbow. J Bone Jt Surg 86:975–982. https://doi.org/10.2106/00004623-200405000-00013
27. Regan W, Morrey B (1989) Fractures of the coronoid process of the ulna. J Bone Jt Surg 71:1348–1354
28. Doornberg JN, van Duijn J, Ring D (2006) Coronoid fracture height in terrible-triad injuries. J Hand Surg 31:794–797. https://doi.org/10.1016/j.jhsa.2006.01.004
29. O'Driscoll SW, Jupiter JB, Cohen MS et al (2003) Difficult elbow fractures: pearls and pitfalls. Instr Course Lect 52:113–134
30. Mason ML (1954) Some observations on fractures of the head of the radius with a review of one hundred cases. Br J Surg 42:123–132. https://doi.org/10.1002/bjs.18004217203
31. Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Jt Surg Am 58:453–458
32. Morrey BF, Sanchez-Sotelo J (2009) The elbow and its disorders, 4th edn. Saunders/Elsevier, Philadelphia
33. Dawson J, Doll H, Boller I et al (2008) The development and validation of a patient-reported questionnaire to assess outcomes of elbow surgery. J Bone Jt Surg Br 90:466–473. https://doi.org/10.1302/0301-620X.90B4.20290
34. Beaton DE, Davis AM, Hudak P et al (2016) The DASH (disabilities of the arm, shoulder and hand) outcome measure: what do we know about it now? Br J Hand Ther 6:109–118. https://doi.org/10.1177/175899830100600401
35. O'Driscoll SW, Bell DF, Morrey BF (1991) Posterolateral rotatory instability of the elbow. J Bone Jt Surg Am 73:440–446
36. Thorngren K-G, Werner CO (2009) Normal grip strength. Acta Orthop Scand 50:255–259. https://doi.org/10.3109/17453677908989765
37. Broberg MA, Morrey BF (1986) Results of delayed excision of the radial head after fracture. J Bone Jt Surg Am 68:669–674
38. Hastings H, Graham TJ (1994) The classification and treatment of heterotopic ossification about the elbow and forearm. Hand Clin 10:417–437
39. Iordens GIT, den Hartog D, Tuinebreijer WE et al (2017) Minimal important change and other measurement properties of the Oxford Elbow Score and the Quick Disabilities of the Arm, Shoulder, and Hand in patients with a simple elbow dislocation; validation study alongside the multicenter FuncSiE trial. PLoS One 12:e0182557. https://doi.org/10.1371/journal.pone.0182557
40. Hartzler RU, Morrey BF, Steinmann SP et al (2014) Radial head reconstruction in elbow fracture-dislocation: monopolar or bipolar prosthesis? Clin Orthop Relat Res 472:2144–2150. https://doi.org/10.1007/s11999-014-3672-0
41. Kyriacou S, Gupta Y, Bains HK et al (2019) Radial head replacement versus reconstruction for the treatment of the terrible triad injury of the elbow: a systematic review and meta-analysis. Arch Orthop Trauma Surg 139:507–517. https://doi.org/10.1007/s00402-019-03111-z
42. Zhang J, Tan M, Kwek EBK (2017) Outcomes of coronoid-first repair in terrible triad injuries of the elbow. Arch Orthop Trauma Surg 137:1239–1245. https://doi.org/10.1007/s00402-017-2733-8
43. Wu H, Liao Q, Zhu Y et al (2012) Surgical reconstruction of comminuted coronoid fracture in terrible triad injury of the elbow. Eur J Orthop Surg Traumatol 22:667–671. https://doi.org/10.1007/s00590-011-0879-6
44. Ring D (2006) Fractures of the coronoid process of the ulna. J Hand Surg 31:1679–1689. https://doi.org/10.1016/j.jhsa.2006.08.020
45. Jeon IH, Sanchez-Sotelo J, Zhao K et al (2012) The contribution of the coronoid and radial head to the stability of the elbow. J Bone Jt Surg Br 94:86–92. https://doi.org/10.1302/0301-620X.94B1.26530
46. Gomide LC, Campos DdO, Ribeiro de Sá JM et al (2011) Terrible triad of the elbow: evaluation of surgical treatment. Rev Bras Ortop (English Edition) 46:374–379. https://doi.org/10.1016/S2255-4971(15)30248-2
47. Antoni M, Eichler D, Kempf J-F et al (2019) Anterior capsule re-attachment in terrible triad elbow injury with coronoid tip fracture. Orthop Traumatol Surg Res 105:1575–1583. https://doi.org/10.1016/j.otsr.2019.09.024
48. Kim B-S, Kim D-H, Byun S-H et al (2020) Does the coronoid always need to be fixed in terrible triad injuries of the elbow? Mid-term postoperative outcomes following a standardized protocol. J Clin Med. https://doi.org/10.3390/jcm9113500
49. Ostergaard PJ, Tarabochia MA, Hall MJ et al (2021) What factors are associated with reoperation after operative treatment of terrible triad injuries? Clin Orthop Relat Res 479:119–125. https://doi.org/10.1097/CORR.0000000000001391
50. Hong CC, Nashi N, Hey HW et al (2015) Clinically relevant heterotopic ossification after elbow fracture surgery: a risk factors study. Orthop Traumatol Surg Res 101:209–213. https://doi.org/10.1016/j.otsr.2014.10.021
51. Bowman SH, Barfield WR, Slone HS et al (2016) The clinical implications of heterotopic ossification in patients treated with radial head replacement for trauma: a case series and review of

the literature. J Orthop 13:272–277. https://doi.org/10.1016/j.jor.2016.06.011
52. Jung S-W, Kim D-H, Kang S-H et al (2019) Risk factors that influence subsequent recurrent instability in terrible triad injury of the elbow. J Orthop Trauma 33:250–255. https://doi.org/10.1097/BOT.0000000000001425
53. Cristofaro CD, Carter TH, Wickramasinghe NR et al (2019) High risk of further surgery after radial head replacement for unstable fractures: longer-term outcomes at a minimum follow-up of 8 years. Clin Orthop Relat Res 477:2531–2540. https://doi.org/10.1097/CORR.0000000000000876
54. Forthman C, Henket M, Ring DC (2007) Elbow dislocation with intra-articular fracture: the results of operative treatment without repair of the medial collateral ligament. J Hand Surg 32:1200–1209. https://doi.org/10.1016/j.jhsa.2007.06.019