Orthopaedics & Traumatology: Surgery & Research 105 (2019) 1575–1583

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

# Anterior capsule re-attachment in terrible triad elbow injury with coronoid tip fracture

Maxime Antoni*, David Eichler, Jean-François Kempf, Philippe Clavert

*Service de chirurgie du membre supérieur, hôpital de Hautepierre 2, CHU Strasbourg, 1, avenue Molière, 67098 Strasbourg cedex, France*

ARTICLE INFO

*Article history:*
Received 25 February 2019
Accepted 16 September 2019

*Keywords:*
Terrible triad injury
Anterior capsule
Elbow
Instability
Dislocation
Coronoid process

ABSTRACT

*Background:* During the surgical treatment of terrible triad elbow injury (TTEI), the usefulness of re-attaching the anterior joint capsule when the coronoid tip is fractured remains unclear. The primary objective of this study was to assess potential benefits during surgery for TTEI of re-attaching the joint capsule when the coronoid tip is fractured.
*Hypothesis:* Re-attaching the anterior joint capsule in TTEI with a fractured coronoid tip improves clinical and radiological outcomes and decreases the complication and revision rates.
*Materials and methods:* This single-centre retrospective study included patients who underwent surgery at the acute phase of TTEI with a fractured coronoid tip. In all patients, a physical examination and elbow radiographs were performed at least 1 year after surgery. A statistical analysis was done to compare the groups with vs. without re-attachment of the anterior capsule and coronoid tip.
*Results:* The study included 30 patients, 16 females and 14 males, with a mean age of 51 years (range: 21–84 years). Among them, 11 did and 19 did not undergo re-attachment. The two groups were comparable regarding demographic features and follow-up duration. No significant differences were found at last follow-up for flexion-extension motion arc ($p = 0.75$), pronation-supination motion arc ($p = 0.3051$), or the Mayo Elbow Performance Score ($p = 0.19$). Radiographic evidence of humero-radial osteoarthritis was significantly more common in the absence of re-attachment ($p = 0.04$), whereas no differences were evidenced regarding humero-ulnar osteoarthritis ($p = 0.73$), the occurrence of subluxation or dislocation ($p = 0.43$), or loosening of the radial head implant ($p = 0.47$). The complication and revision rates were similar in the two groups.
*Conclusion:* In our experience, re-attaching the anterior capsule during the surgical treatment of TTEI with a coronoid tip fracture did not improve the clinical or radiographic outcomes after a mean follow-up of 54 months.
*Level of evidence:* IV, retrospective study.



## 1. Introduction

Terrible triad elbow injury (TTEI) [1] combines posterolateral dislocation, a radial head fracture, and a coronoid process fracture. The word "terrible" refers to the extreme instability of the lesion. Surgery is needed in virtually all patients [2–7], with very few carefully selected exceptions [6,7]. Surgery for TTEI [2–4,8–13] involves re-attaching the lateral collateral ligaments [16], fixing the radial head fracture or implanting a prosthetic head, and fixing the coronoid process fracture. The coronoid process is the site of attachment not only of the anterior capsule but also, and more importantly, of the anterior bundle of the medial collateral ligament, on the antero-medial facet. Re-attachment of the medial collateral ligament onto the medial epicondyle is performed only when the previous procedures fail to eliminate medial valgus instability [2–4,14,15].

Internal fixation of the coronoid process is recommended [16,17] when the fracture involves either the base (type 3 according to Regan and Morrey [18] or O'Driscoll [19]) or the antero-medial facet (type 2 according to O'Driscoll) with its medial collateral ligament insertion. The fracture may involve the tip of the coronoid process (type 1 according to Regan and Morrey or O'Driscoll), which does not receive any ligament insertions [17,20,21]. The main effect of fixing the coronoid tip is therefore to re-attach the anterior capsule. However, published data on this point are conflicting [2,10,17,19] and the optimal management of coronoid tip fractures remains controversial.

* Corresponding author.
*E-mail address:* dr.maxime.antoni@gmail.com (M. Antoni).

https://doi.org/10.1016/j.otsr.2019.09.024
1877-0568/

The primary objective of this study was to assess potential benefits during surgery for TTEI of re-attaching the joint capsule when the coronoid tip is fractured. To this end, groups managed with and without re-attachment were compared. The working hypothesis was that re-attaching the anterior joint capsule in TTEI with a fractured coronoid tip improves clinical and radiological outcomes and decreases the complication and revision rates.

## 2. Material and methods

### 2.1. Population

Consecutive patients managed surgically for TTEI at the orthopaedic and trauma surgery department of the university hospital in Strasbourg, France, were identified retrospectively. Patients were included if surgery was performed within 3 weeks after TTEI, the coronoid tip was fractured (type 1 according to Regan and Morrey [18] or to O'Driscoll [19]), and a follow-up evaluation was performed at least 1 year after surgery. Exclusion criteria were the presence of multiple injuries, resection of the entire radial head, non-operative treatment, and treatment by external fixation only.

Of the 75 patients managed surgically for TTEI during the study period (2007–2017), 36 had a coronoid tip fracture, including 6 who were lost to follow-up or declined to attend a re-evaluation visit. This left 30 patients for the study, 16 females and 14 males with a mean age of 51 year (range: 21–84 years), who met all the study inclusion and exclusion criteria. For the statistical analysis, the patients were divided into two groups based on whether they did or did not undergo anterior capsule re-attachment during the surgical treatment ($n = 11$ and $n = 19$, respectively).

### 2.2. Initial injuries

The injury occurred during a fall from standing height in 22/30 (73%) patients, a high-energy sport in 5/30 (17%), and a fall from an elevation in 3/30 (10%) patients. The elbow was the only injured site in 28/30 (93%) patients, whereas 2/30 (7%) patients also had injuries at other sites. The dominant upper limb was involved in 14/30 (47%) patients. Standard radiographs were obtained before surgery in all patients. In addition, 18/30 (60%) patients underwent computed tomography (CT). Traumatic radial nerve palsy was a feature in 2 patients and another patient had an open skin wound.

### 2.3. Surgical management modalities

Mean time from injury to surgery was 3.9 days (range: 0–13 days). Surgery was performed on an emergent basis on the day of the injury in 7 patients and a few days after emergency reduction of the dislocation in the other 23 patients. The lateral approach was used in all 30 patients. In addition, a medial approach was performed in 4/30 (13%) patients to attach the medial collateral ligament to the medial epicondyle.

The anterior capsule and coronoid tip were re-attached in 11/30 (37%) patients, usually with an anchor (9/11, 82%) and less often with trans-osseous tunnels (2/11, 18%). In the remaining 19/30 (63%) patients, the anterior capsule and coronoid tip were not re-attached.

The radial head fracture was treated by implantation of a prosthesis in 22/30 (73%) patients, screw-plate fixation in 5/30 (17%) patients, and excision of a fragment that was too small to be fixed in 3/30 (10%) patients. In 25/30 (83%) patients, the collateral ligament was re-attached using an anchor or trans-osseous stitches.

Postoperative immobilisation was with a long-arm cast in 22/30 (73%) patients, an external fixator in 6/30 (20%) patients, and a hinged splint in 2/30 (7%) patients. Mean duration of immobilisation was 3.3 weeks (range: 2–6 weeks).

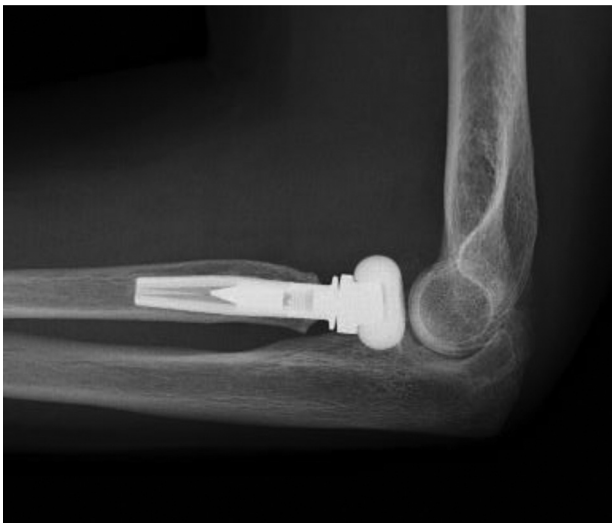

**Fig. 1.** Successful reduction restoring normal elbow anatomy.

**Fig. 2.** Lateral radiograph: subluxation of the elbow.

### 2.4. Clinical and radiological evaluation at last follow-up

The complications were recorded throughout follow-up. The work-up at last follow-up included a physical examination with motion range measurements and determination of the Mayo Elbow Performance Score (MEPS [22]). In addition, standard antero-posterior and lateral radiographs of the affected elbow were obtained routinely and used to detect subluxation or dislocation (Figs. 1–3) on the lateral view, narrowing of the humero-ulnar (Fig. 4), humero-radial (Fig. 5), or overall (Fig. 6) joint line assessed using the four-grade Broberg and Morrey classification [23], and loosening of the radial head implant if present (Fig. 7). The Broberg and Morrey classification [23] distinguishes four grades of elbow osteoarthritis: 0, normal joint with no joint line narrowing; 1, slight joint line narrowing and minimal osteophytosis; 2, moderate joint line narrowing (> 50%) and osteophytosis; and 3, severe degenerative changes with gross destruction of the joint.

### 2.5. Statistical analysis

Quantitative variables were described as mean ± SD when normally distributed and as median [interquartile range] otherwise.

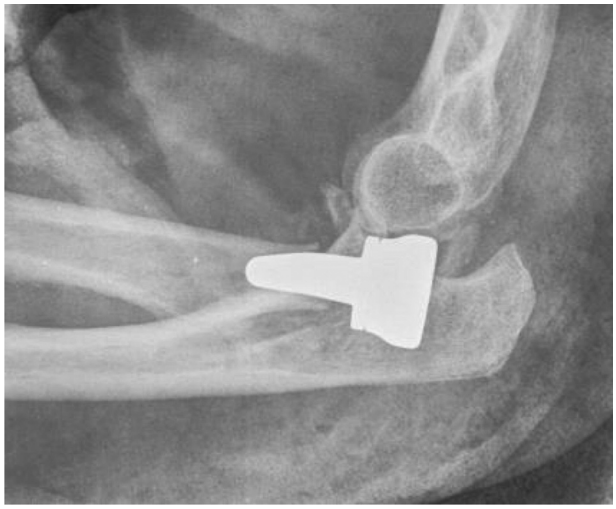

**Fig. 3.** Complete dislocation of the elbow.

**Fig. 4.** Medial humero-ulnar joint line narrowing > 50%.

Qualitative variables were described as *n* (%). For between-group comparisons of quantitative variables, Student's test or ANOVA was used if the Shapiro–Wilk indicated a normal distribution and Fisher's or Bartlett's homoscedasticity test was not significant; otherwise, the Wilcoxon or Kruskal–Wallis test was applied. Post-hoc analyses were done using Student's or Wilcoxon's test with Holm's method to correct the alpha risk. Proportions were compared between groups by applying the $Chi^2$ test or Fisher's test. Spearman's method was chosen to compute correlation coefficients, given the non-normal distribution of the variables under consideration. Values of $p \leq 0.05$ were considered significant. R version 3.3.3 R Core Team was used to perform the statistical analyses.


**Fig. 5.** Capitellar osteoarthritis.

## 3. Results

### 3.1. Population

The groups with and without anterior capsule re-attachment were not significantly different for age at surgery ($p = 0.43$), involvement of the dominant upper limb ($p = 0.39$), time from injury to surgery ($p = 0.39$), procedure used to manage the radial head fracture (implant, internal fixation, or fragment excision) ($p = 0.16$), or duration of postoperative immobilisation ($p = 0.64$).

### 3.2. Clinical outcomes

Mean follow-up was 54.4 months (range: 12–131 months) (Table 1). In the overall population at last follow-up, mean MEPS was 85.3 (range: 65–100), mean flexion-extension range was 111.2° (55°–145°), and mean pronation-supination range was 155.3° (range: 20°–180°). When the two groups were compared, no significant differences were found for the motion arc ranges or MEPS.

**Fig. 6.** Advanced global osteoarthritis of the elbow.

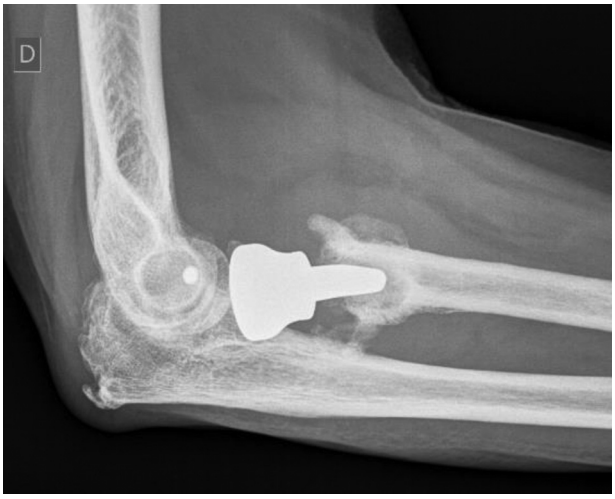


**Fig. 7.** Loosening of the radial head implant.

### 3.3. Radiological outcomes

At last follow-up, the only significant difference between the two groups was a higher prevalence of humero-radial osteoarthritis in the group without anterior capsule re-attachment ($p = 0.04$) (Table 2). None of the other radiological parameters differed significantly between the two groups.

### 3.4. Complications and revision operations

Intra- or postoperative complications occurred in 14/30 (47%) patients, including 7/11 (64%) in the group with and 7/19 (37%) in the group without anterior capsule re-attachment ($p = 0.56$) (Table 3).

Only 2 patients, both in the group with re-attachment, experienced intraoperative complications. In both patients, implantation of the humeral pin of the external fixator caused a radial nerve injury. One patient recovered fully and the other partially. No intraoperative complications related to anterior capsule re-attachment were recorded.

Revision surgery was required in 12/30 (40%) patients, including 8 who required more than one additional procedure. The remaining 2 complications that did not require revision surgery were the above-described radial nerve injuries.

**Table 1**
Clinical outcomes in the groups with and without re-attachment of the anterior capsule and fractured coronoid tip.

| | Re-attachment | No re-attachment | *p*-value |
|---|---|---|---|
| Flexion, mean (range),° | 132 (120–140) | 128 (100–150) | 0.3026 |
| Loss of extension, mean (range),° | 23 (5–45) | 16 (0–45) | 0.1561 |
| Flexion-extension motion arc, mean (range),° | 109.5 (75–135) | 112.2 (55–145) | 0.75 |
| Pronation, mean (range),° | 85 (75–90) | 77 (10–90) | 0.1465 |
| Supination, mean (range),° | 79 (45–90) | 74 (0–90) | 0.5 |
| Pronation-supination motion arc, mean (range),° | 163 (120–180) | 151 (20–180) | 0.3051 |
| MEPS, mean (range), points | 82 (65–95) | 87 (75–100) | 0.1935 |

MEPS: Mayo Elbow Performance Score.

**Table 2**
Radiological outcomes in the groups with and without re-attachment of the anterior capsule and fractured coronoid tip.

| | Re-attachment | No re-attachment | *p*-value |
|---|---|---|---|
| Lateral distraction on the AP view | 18% (2/11) | 0% (0/19) | 0.06 |
| Subluxation or dislocation on the lateral view | 0% (0/11) | 5% (1/19) | 0.43 |
| Humero-ulnar OA (Broberg and Morrey grade 2 or 3) | 27% (3/11) | 32% (6/19) | 0.73 |
| Capitular OA (Broberg and Morrey grade 2 or 3) | 27% (3/11) | 63% (12/19) | **0.0394** |
| Loosening of the radial head implant | 33% (2/6) | 19% (3/16) | 0.47 |

AP: antero-posterior; OA: osteoarthritis. In bold, the statistical significance between the 2 groups, as $p < 0,05$.

**Table 3**
Complications and revision procedures.

| | Patients | Complications | Number of revision procedures per patient | Revision procedures |
|---|---|---|---|---|
| No re-attachment, *n* = 19 | 1 | Stiffness and proximal radio-ulnar synostosis | 1 | Joint release and radial head implant exchange after 6 months |
| | 2 | Early recurrent dislocation | 2 | External fixator installed on day 6<br>External fixator removed after 1 month |
| | 3 | Radial head implant loosening with pain | 1 | Radial head implant removed after 42 months |
| | 4 | Early recurrent dislocation | 2 | Radial head implant exchange and external fixator installation on day 7<br>External fixator removed after 6 weeks |
| | 5 | Stiffness | 1 | Radial head implant removed after 5 months |
| | | Stiffness then chronic instability | 2 | Radial head implant removed after 5 months<br>Repositioning of the radial head implant and lateral collateral ligament repair after 18 months |
| | 6 | Compression of ulnar nerve | 2 | External fixator removed after 6 weeks<br>Ulnar nerve release after 5 years |
| | 7 | Destruction of the capitulum, advanced overall osteoarthritis of the elbow | 5 | External fixator removed after 1 month<br>Radial head implant removed and new external fixator installed after 6 months<br>External fixator removed after 8 months<br>Total Conrad Morrey elbow prosthesis after 2 years |
| Re-attachment, *n* = 11 | 1 | Early recurrent dislocation | 3 | External fixator installed on day 2<br>External fixator removed after 6 weeks<br>Radial head implant after 1 year |
| | 2 | Early recurrent dislocation | 2 | External fixator installed on day 2<br>External fixator removed after 6 weeks |
| | 3 | Stiffness | 1 | Manipulation under anaesthesia after 2 months |
| | 4 | Complete sensory-motor radial nerve injury related to an external fixator pin | 0 | Partial recovery |
| | 5 | Early recurrent dislocation | 3 | Humero-ulnar arthroereisis by two pins on day 0<br>External fixator installed on day 2 with a medial approach to re-attach the medial collateral ligament and repair the coronoid tip and lateral collateral ligament<br>External fixator removed after 6 weeks |
| | 6 | Stiffness | 1 | Joint release after 2 years |
| | 7 | Complete sensory-motor radial nerve injury related to an external fixator pin | 1 | Complete spontaneous recovery of radial nerve function<br>External fixator removal after 6 weeks |

## 4. Discussion

We evaluated the clinical and radiological effects of re-attaching the anterior capsule in patients with coronoid tip fractures as part of TTEI. Our results do not support the working hypothesis, as re-attachment was not associated with better outcomes in our population.

Many studies (Table 4) have reported the outcomes of treatments for TTEI [2,5,9,10,12–15,24–31], although most provide a fairly low level of evidence [22]. Surgery was performed in the vast majority of cases [2,3,8–13]. However, a few highly selected patients were found eligible for non-operative treatment [6,7]. The surgical management of TTEI [2,5,9–15,24,32] typically involves re-attaching the lateral collateral ligament, fixing or replacing the radial head, and re-attaching the coronoid fragment. Appropriate surgical management has produced good outcomes similar to those in our population [5,8,9,12,13]. Thus, mean MEPS values ranged from 78 to 96, mean flexion-extension from 92° to 127°, and mean pronation-supination from 126° to 156°.

The optimal treatment of the coronoid fracture remains debated and varies with the size of the fragment. When the fracture line is at the base of the coronoid process (type 3 according to Regan and Morrey or O'Driscoll), internal fixation is mandatory to restore the anterior bony abutment that prevents antero-posterior translation of the ulna. Fractures of the antero-medial facet (type 2 according to O'Driscoll) often detach the ulnar insertion of the medial collateral ligament. This lesion must be clearly identified by preoperative CT scanning and the ligament must then be re-attached to restore medial stability of the elbow. In patients with TTEI, internal fixation of the coronoid fracture is classically recommended [9,11,17,33,34] if the footprint of the anterior bundle of the medial collateral ligament on the antero-medial facet is involved [21]. This ensures re-attachment of the ligament, thereby improving medial stability of the elbow [9]. However, in most cases of TTEI, the coronoid fracture involves only the tip of the coronoid process (type 1 according to Regan and Morrey or O'Driscoll) [17,35]. In this situation, the medial collateral ligament is theoretically intact, as only the anterior capsule attaches to the tip of the coronoid process [17,21].

The anatomical studies by Cage et al. [21], Shimura et al. [36], and Ablove et al. [37] have confirmed that no ligaments attach to the tip of the coronoid process. The anterior capsule attachment site was located 2.36 mm [37] to 6.4 mm [21] distal to the coronoid tip. Therefore, the main effect of coronoid tip fixation is to re-attach the anterior capsule. A study by Luokkala et al. involving routine magnetic resonance imaging in patients with elbow dislocation showed that the anterior capsule attachment site was involved in 71% of cases [38]. Apart from theoretical considerations, whether anterior capsule re-attachment confers clinical benefits

**Table 4**
Literature review.

| 1st author | Journal | Year | *n* of patients | Mean age (range), years | Mean follow-up (months) | Mean flexion-extension motion arc (°) | Mean pronation-supination motion arc (°) | Prevalence of OA at last follow-up (%) | Broberg and Morrey score | MEPS | DASH | Complication rate (OA excluded) (%) | Details on complications | Revision rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Papatheodorou | *Clin Orthop Relat Res* | 2014 | 14 | 52 (32–58) | 41 (24–56) | 123 (75–140)° | 145 (70–170)° | 7.1 | 90 (70–100) | – | 14 (0–38) | 7.1 | Heterotopic ossifications | 7.1 |
| Giannicola | *Injury* | 2015 | 26 | 52 (28–81) | 31 (12–87) | 127 (70–155)° | 156 (20–175)° | 38.5 | – | 96 (100–70) | – | 42.3 | Stiffness, ulnar neuropathy, instability, fixation material migration | 23.1 |
| Pugh | *JBJS Am* | 2004 | 36 | 41.4 (13–76) | 34 (20–65) | | | – | – | 88 (45–100) | – | 30.6 | Stiffness, synostosis, instability, infection, heterotopic ossifications | 22.2 |
| Forthman | *J Hand Surg Am* | 2007 | 22 | 48 (24–75) | 29 (12–53) | 120° (65–145) | 142° (0–175) | 31.8 | 88 (53–100) | 89 (65–100) | 13.3 (0–43) | 40.9 | Ulnar neuropathy, stiffness, instability | 40.9 |
| Egol | *Bull NYU Hosp Jt Dis* | 2007 | 37 | 52.9 (28–79) | 27 (12–105) | 109° (45–140) | 128° (15–165) | – | 77 (33–100) | 81 (45–100) | 28 (0–72) | 24.3 | Instability, stiffness, radial head implant loosening, heterotopic ossifications, ulnar neuropathy, CRPS-I | 17.2 |
| Lindenhovius | *J Hand Surg Am* | 2008 | 18 | 47 (22–76) | 29 (10–53) | – | – | 66.7 | 90 (64–100) | 88 (65–100) | 15 (0–43) | 27.8 | Stiffness, ulnar neuropathy | 27.8 |
| Leigh | *J Soulder Elbow Surg* | 2012 | 23 | 43.5 (19–67) | 40.6 (16–73) | 121° (90–140) | 134° (65–175) | – | – | – | 9 (0–18) | 26.1 | Radial head non-union, fixation material migration, instability, infection, stiffness | 26.1 |

Table 4 (*Continued*)

| 1st author | Journal | Year | *n* of patients | Mean age (range), years | Mean follow-up (months) | Mean flexion-extension motion arc (°) | Mean pronation-supination motion arc (°) | Prevalence of OA at last follow-up (%) | Broberg and Morrey score | MEPS | DASH | Complication rate (OA excluded) (%) | Details on complications | Revision rate (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Garrigues | *JBJS Am* | 2011 | 40 | 48 (22–76) | 24 (18–53) | 115° (75–140) | – | – | 90 (64–100) | – | – | 70 | Instability, oversized radial head implant, non-union, mal-union, fixation material migration, heterotopic ossifications | 27.5 |
| Seijas | *J Orthop Surj (Hong Kong)* | 2009 | 18 | 45 (12–77) | 13.6 (4–38) | – | – | 5.6 | – | – | – | 88.9 | Instability, radio-ulnar synostosis, ulnar neuropathy, heterotopic ossifications | 33 |
| Chemama | *Orthop Traumatol Surg Res* | 2010 | 13 | – | 63 (15–128) | – | – | 7.7 | – | 87 (75–100) | – | 15.4 | Instability, lateral pain | 15.4 |
| Winter | *Chir Main* | 2009 | 13 | 40 (18–77) | 25 (15–48) | – | – | – | 86.5 (55–100) | – | – | 61.5 | Instability, radial head implant diassembly, infection, stiffness, capitular erosion, heterotopic ossifications | 46.2 |
| Zeiders | *JBJS Am* | 2008 | 32 | – | 36 (12–60) | – | – | – | – | – | 23 (19–28) | 3.1 | Heterotopic ossifications | 0 |
| Ring | *JBJS Am* | 2002 | 11 | 49 (17–67) | – | 92° (40–130) | 126° (40–170) | 70 | 76 (34–98) | – | – | 63.6 | Synostosis, instability, neuropathy | 54.5 |
| Pierrart | *Injury* | 2015 | 18 | 43.8 (19–56) | 31.5 (7–97) | 114° (70–140) | – | 52.9 | – | 77.8 (25–100) | – | 38.9 | Infection, instability, radial head implant disassembly, ulnar neuropathy, radio-ulnar synostosis | – |

OA: osteoarthritis; MEPS: Mayo Elbow Performance Score; DASH: Disabilities of Arm, Shoulder, and Hand score; CRPS-I: complex regional pain syndrome type I.

remains to be established [35,39,40], as the potential stabilising effect of the capsule is unclear. Furthermore, fixation of the coronoid fragment is often difficult to achieve via the lateral approach, notably when the radial head is present. The conflicting nature of published data [7,24] and absence of a control group in the available studies preclude a definitive conclusion on this point.

To our knowledge, our cohort study is the largest to date designed to determine whether anterior capsule re-attachment is beneficial in patients with a coronoid tip fracture as part of TTEI. We were able to compare patients with vs. without re-attachment. The two groups were not significantly different regarding the clinical outcomes, the frequency of humero-ulnar osteoarthritis, the complication rate, or the need for revision surgery. Humero-radial osteoarthritis was significantly more common at last follow-up in the group without re-attachment. Thus, our results indicate that re-attaching the anterior capsule in patients with coronoid tip fractures as part of TTEI provides little benefit. Previous studies support our findings. Thus, in a biomechanical cadaver study by Beingessner et al. [35], fixation of coronoid tip fractures did not modify elbow kinematics if the ligaments and radial head had been repaired. These authors did not recommend coronoid tip fixation in patients with TTEI. Papatheodorou et al. [41] studied 14 patients with TTEI whose surgical treatment did not involve repairing the coronoid fractures (which were type 1 or 2 according to Regan and Morrey). There was no control group. The clinical and radiographic outcomes were consistent with previous publications. The authors concluded that coronoid fractures did not require repair when the elbow was stable after repair of the lateral collateral ligament and radial head.

Few data are available on the risk of osteoarthritis after surgery for TTEI. Osteoarthritis occurred in 6% to 70% of patients [5,7,9,12,13], in keeping with our findings. The only statistically significant difference between our two groups was a higher risk of humero-radial osteoarthritis in the group without anterior capsule re-attachment. The most likely explanation is persistent postero-lateral instability in the absence of re-attachment, increasing the risk of degenerative changes in the lateral compartment.

The complication and revision rates were fairly high in our population (47% and 40%, respectively). Persistent instability and stiffness were the main complications. In earlier studies, complications occurred in up to 89% of patients after surgery for TTEI (Table 4). Most of the complications in our patients occurred postoperatively. No intraoperative complications related to anterior capsule re-attachment were recorded. Thus, re-attaching the anterior capsule does not seem to be a source of injury or to carry any morbidity per se.

The main limitation of this study is the retrospective design, with its inherent biases. Although prospective recruitment would have been preferable, the low incidence of TTEI would have resulted in a long recruitment time and would perhaps have required the participation of multiple centres in order to obtain an adequate sample size more rapidly. The absence of randomisation is another source of bias, as the reasons that guided decisions about anterior capsule re-attachment may have resulted in differences between the groups. For instance, a sensation of persistent instability at the end of the surgical procedure may have prompted adjunctive capsule re-attachment. On the opposite, a subjective sensation of good elbow stability may have led surgeons who usually performed capsule re-attachment to dispense with this procedure. Measurement of the radio-capitellar ratio [42–44] on the lateral radiographs would have provided a more accurate assessment of posterior radial head translation. Finally, the small sample size limited the statistical power of the analysis. However, the number of patients was large compared to earlier studies.

## 5. Conclusion

Re-attaching the anterior capsule as part of the surgical treatment of TTEI with a coronoid tip fracture was not associated with improved outcomes after a mean follow-up of 54 months in our population. Although degenerative changes of the humero-radial joint were more common at last follow-up in the group without re-attachment, humero-ulnar osteoarthritis, complications, and revision procedures occurred with similar frequencies in the two groups. When the radial head is present, anterior capsule re-attachment may be challenging to perform through the lateral approach only. Therefore, provided the other stabilising structures are repaired, re-attaching the anterior capsule would not seem indispensable. The situations in which anterior capsule re-attachment may be preferable remain to be identified.

## Disclosure of interest

The authors declare that they have no competing interest.

## Funding

None.

## Contributions of each author

Maxime Antoni designed the study, reviewed the medical files, re-evaluated the patients, and drafted the manuscript.

David Eichler, Jean-François Kempf, Philippe Clavert revised the manuscript for important intellectual content.

## References

[1] Hotchkiss RN. Fractures and dislocations of the elbow. In: Rockwood CA, Grenn DP, Bulchoz RW, Heckman JD, editors. Rockwood and Green's fractures in adults, 1. 4th ed. Philadelphia: Lippincott-Raven; 1996. p. 929–1024.
[2] Mathews P, Athwal G, King GJW. Terrible triad injury of the elbow: current concepts. J Am Acad Orthop Surg 2009;17:137–51.
[3] Sanchez-Sotelo J, Morrey M. Complex elbow instability: surgical management of elbow fracture dislocations. EFORT Open Rev 2016;1:183–90.
[4] Mansat P, Bonnevialle N. Luxations du coude. EMC Appareil locomoteur Paris: Elsevier Masson SAS; 2009 [14-042-A-10].
[5] Rodriguez-Martin J, Pretell-Mazzini J, Andres-Esteban E, Larrainzar-Garijo R. Outcomes after terrible triads of the elbow treated with the current surgical protocols. A review. Int Orthop 2011;35:851–60.
[6] Chan K, MacDermid JC, Faber KJ, King GJW, Athwal G. Can we treat select terrible triad injuries nonoperatively? Clin Orthop Relat Res 2014;472:2092–9.
[7] Najd Mazhar F, Jafari D, Mirzaei A. Evaluation of functional outcome after non-surgical management of terrible triad injuries of the elbow. J Shoulder Elbow Surg 2017;26:1342–7.
[8] Giannicola G, Calella P, Piccioli A, Scacchi M, Gumina S. Terrible triad of the elbow: is it a troublesome injury? Injury 2015;46:S68–76.
[9] Pugh DM, Wild LM, Schemitsch EH, King GJ, McKee MD. Standard surgical protocol to treat elbow dislocations with radial head and coronoid fractures. J Bone Joint Surg Am 2004;86:1122–30.
[10] McKee MD, Pugh DMW, Wild LM, Schemitsch EH, King GJW. Standard surgical protocol to treat elbow dislocations with radial head and coronoid fractures. J Bone Joint Surg Am 2005;87:22–32.
[11] Kovacevic D, Vogel LA, Levine WN. Complex elbow instability. Radial head and coronoid. Hand Clin 2015;31:547–56.
[12] Egol KA, Immerman I, Paksima N, et al. Fracture dislocation of the elbow. Functional outcome following treatment with a standardized protocol. Bull NYU Hosp Jt Dis 2007;65:273–370.
[13] Forthman C, Henket M, Ring DC. Elbow dislocation with intra-articular fracture: the result of operative treatment without repair of the medial collateral ligament. J Hand Surg 2007;32:1200–9.
[14] Chemama B, Bonnevialle N, Peter O, Mansat P, Bonnevialle P. Terrible triad injury of the elbow: how to improve outcomes? Orthop Trauma Surg Res 2010;96:147–54.
[15] Pierrart J, Bégué T, Mansat P, GEEC. Terrible triad of the elbow: treatment protocol and outcome in a series of eighteen cases. Injury 2015;46:S8–12.
[16] Park SM, Lee JS, Jung JY, Kim JY, Song KS. How should anteromedial coronoid facet fracture be managed? A surgical strategy based on O'Driscoll classification and ligament injury. J Soulder Elbow Surg 2015;24:74–82.
[17] Ring D. Fractures of the coronoid process of the ulna. J Hand Surg Am 2006;31:1679–89.

[18] Regan WD, Morrey BF. Fractures of the coronoid process of the ulna. J Bone Joint Surg Am 1989;71:1348–54.
[19] Sanchez-Sotelo J, O'Driscoll SW, Morrey BF. Medial oblique compression fracture of the coronoid process of the ulna. J Shoulder Elbow Surg 2005;14:60–4.
[20] Doornberg JN, Ring D. Coronoid fracture patterns. J Hand Surg Am 2006;31:45–52.
[21] Cage DJ, Abrams RA, Callahan JJ, Botte MJ. Soft tissue attachments of the ulnar coronoid process. An anatomic study with radiographs correlation. Clin Orthop Relat Res 1995;320:154–8.
[22] Morrey BF, An KN. Functional evaluation of the elbow. In: Morrey BF, editor. The elbow and its disorders. 2nd ed. Philadelphia, PA: WB Saunders; 1993. p. 86–97.
[23] Broberg MA, Morrey BF. Results of treatment of fracture-dislocations of the elbow. Clin Orthop Relat Res 1987;216:109–19.
[24] Chen HW, Liu GD, Wu LJ. Complications of treating terrible triad injury of the elbow: a systematic review. Plos One 2014;9:e97476.
[25] Garrigues GE, Wray 3rd WH, Lindenhovius AL, Ring DC, Ruch DS. Fixation of the coronoid process in elbow fracture-dislocations. J Bone Joint Surg Am 2011;93:1873–81.
[26] Leigh WB, Ball CM. Radial head reconstruction versus replacement in the treatment of terrible triad injuries of the elbow. J Shoulder Elbow Surg 2012;21:1336–41.
[27] Seijas R, Ares-Rodriguez O, Orellana A, Albareda D, Collado D, et al. Terrible triad of the elbow. J Orthop Surg (Hong Kong) 2009;17:335–9.
[28] Winter M, Chuinard C, Cikes A, Pelegri C, Bronsard N, et al. Surgical management of elbow dislocation associated with non-reparable fractures of the radial head. Chir Main 2009;28:158–67.
[29] Zeiders GJ, Patel MK. Management of unstable elbows following complex fracture-dislocations—the "terrible triad" injury. J Bone Joint Surg Am 2008;90:75–84.
[30] Lindenhovius AL, Jupiter JB, Ring D. Comparison of acute versus subacute treatment of terrible triad injuries of the elbow. J Hand Surg Am 2008;33:920–6.
[31] Ring D, Jupiter JB, Zilberfarb J. Posterior dislocation of the elbow with fractures of the radial head and coronoid. J Bone Joint Surg Am 2002;84-A:547–51.
[32] Schneeberger AG, Sadowski MM, Jacob HA. Coronoid process and radial head as posterolateral rotatory stabilizers of the elbow. J Bone Joint Surg Am 2004;86:975–82.
[33] Closkey RF, Goode JR, Kirschenbaum D, Cody RP. The role of the coronoid process in elbow stability. A biomechanical analysis of axial loading. J Bone Joint Surg Am 2000;82-A:1749–53.
[34] Jeon IH, Sanchez-Sotelo J, Zhao K, An KN, Morrey BM. The contribution of the coronoid and radial head to the stability of the elbow. J Bone Joint Surg Br 2012;94:86–92.
[35] Beingessner DM, Stacpoole RA, Dunning CE, Johnson JA, King GJW. The effect of suture fixation of type 1 coronoid fractures on the kinematics and stability of the elbow with and without medial collateral ligament repair. J Shoulder Elbow Surg 2007;16:213–7.
[36] Shimura H, Nimura A, Nasu H, Fujishiro H, Imatani J, Okawa A, et al. Joint capsule attachment to the coronoid process of the ulna: an anatomic study with implications regarding the type 1 fractures of the coronoid process of the O'Driscoll classification. J Shoulder Elbow Surg 2016;25:1517–22.
[37] Ablove RH, Moy OJ, Howard C, Peimer CA, S'Doia S. Ulnar coronoid process anatomy. Possible implications for elbow instability. Clin Orthop Relat Res 2006;449:259–61.
[38] Luokkala T, Temperley D, Basu S, Karjalainen TV, Watts AC. Analysis of magnetic resonance imaging–confirmed soft tissue injury pattern in simple elbow dislocations. J Shoulder Elbow Surg 2019;28:341–8.
[39] Terada N, Yamada H, Seki T, Urabe T, Takayama S. The importance of reducing small fractures of the coronoid process in the treatment of unstable elbow dislocation. J Shoulder Elbow Surg 2000;9:344–6.
[40] Cohen MS. Fracture of the coronoid process. Hand Clin 2004;20:443–53.
[41] Papatheodorou LK, Rubright JH, Heim KA, Weiser RW, Sotereanos DG. Terrible triad injuries of the elbow: does the coronoid always need to be fixed? Clin Orthop Relat Res 2014;472:2084–91.
[42] McCann F, Canet F, Sandman E, Petit Y, Rouleau DM. Does radiographic beam angle affect the radiocapitellar ratio measurement of subluxation in the elbow? Clin Orthop Relat Res 2013;471:2556–62.
[43] Sandman E, Canet F, Petit Y, Laflamme GY, Athwal GS, Rouleau DM. Effect of elbow position on radiographic measurements of radio-capitellar alignment. World J Orthop 2016;7:117–22.
[44] Rouleau DM, Sandman E, Canet F, Djahangiri A, Laflamme Y, Athwal GS, et al. Radial head translation measurement in healthy individuals: the radiocapitellar ratio. J Shoulder Elbow Surg 2012;21:574–9.