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Olecranon Fractures

"Olecranon Fractures: A Critical Analysis Review"

Introduction

Fracture of the olecranon process is the most common injury to the proximal ulna and accounts for approximately 18% of proximal forearm fractures[1]. The severity of injury varies from a simple olecranon fracture to a complex Monteggia/Monteggia-like injury[2]. **Fractures of the olecranon process may be considered intra-articular with extension into the greater sigmoid notch or extra-articular avulsion injuries of the triceps tendon insertion.** The management of displaced fractures has consisted of surgical fixation based on fracture characteristics and ulnohumeral stability[3-7]. Recent evidence has highlighted good outcomes with non-operative management even with displaced fractures in the older population, avoiding the risks associated with surgery[8-11]. The aim of this review is to critically **analyze** the current evidence in the management of isolated traumatic olecranon fractures.

Anatomy

The olecranon process plays a key role in elbow stability. The ulnohumeral articulation is **the primary osseous stabilizer of the elbow and resembles** a complex spiral hinge between the humeral trochlea and ulna greater sigmoid notch. **The sigmoid notch can be divided into three zones, anterior-articular surface, posterior-articular surface, with 2 facets in each, and intervening zone which is the non-loadbearing bare area. The posterior zone consists of the olecranon process with the posterolateral and posteromedial facets, the anterior zone the anteromedial and anterolateral facet of the coronoid providing a four-facet support for the forearm on the end of the humerus. An analogy can be made with the hull of a boat (being the humerus) out of the water balanced on a 4-legged cradle (the four facets) (Figure 1). Care must be taken to ensure that the anterior and posterior**

articular surfaces are well apposed against the trochlea. It is not necessary to elevate impaction fractures of the bare area in most cases as this is a non-loadbearing area. The olecranon process prevents anterior translation of the ulna with respect to the distal humerus, and the coronoid process prevents posterior translation. The two work in concert to control varus and valgus displacement. The bare area, lacking hyaline cartilage, between the coronoid and olecranon processes is frequently the site of fracture and care should be taken not to over-compress this area **during open reduction and internal fixation as this can lead to narrowing** of the sigmoid notch and joint incongruency.

It is a common error to assume the ulna is a straight bone. Several anatomical and radiological studies **improved our knowledge of the anatomy of the proximal ulna[12-15]**. Two angles have shown clinical importance when the olecranon is managed surgically. The dorsal bowing of the proximal ulna known as the Proximal Ulna Dorsal Angulation (PUDA) is important to reconstruct and a mal-reduced PUDA of ≥5° can lead to substantial loss in the flexion/extension arc range of movement (ROM)[13, 15]. It is also important to reconstruct the anteromedial angulation which is commonly known as the Varus Angle (VA). A mal-reduced VA can lead to loss in elbow extension/flexion and pronation/supination ROM[16]. This is more important with an intramedullary screw or straight plate osteosynthesis which can lead to mal-reduction and opening at the fracture site. **A medial entry point during screw fixation can cause a mal-reduction of the VA leading to an articular step-off[14].**

The proximal third of the olecranon **acts** as an insertion point for the triceps muscle which is the main deforming force in the displaced fracture. The triceps footprint consists of a deep muscular and a superficial tendinous part[17]. The compression of the plate on the tendinous part can explain the irritational symptoms some patients experience following a direct posterior plate fixation, therefore, some surgeons advocate making a small split in the tendon insertion to accommodate for the plate, which can then be repaired at end of the procedure.

Mechanism of injury:

Olecranon fractures **occur** due to direct trauma, indirect trauma, or repetitive overuse injury. The olecranon process is at risk of fracture during a direct trauma due to its subcutaneous location. A cadaveric study has shown that olecranon fractures usually occur when the elbow is flexed to 90° and the olecranon is impacted into the distal humerus causing a multi-fragmentary fracture configuration[18]. Indirect traumatic fractures are caused by the forceful eccentric contraction of the triceps muscle during a fall onto an outstretched hand causing a transverse or short oblique fracture. It is essential to differentiate those injures from elbow fracture-dislocations during clinical and radiographic assessment as they can have a similar mechanism of injury. Stress fractures are less common and usually **occur** in professional throwing athletes, especially baseball players, due to repetitive microtrauma to the olecranon caused by the throwing motion[19]. This review will focus on the management of traumatic olecranon fractures.

Classification

Several classification systems are described in the literature to classify fractures of the olecranon based on a combination of fracture displacement, configuration, fragmentation, and/or elbow instability. The main limitation of the current classifications is the low reproducibility with fair to moderate inter/intra-observer reliability[20]. The Colton classification was the first described and classified olecranon fractures into undisplaced type-1 and displaced type-2 fractures, type-2 is further subdivided into four categories: avulsion, transverse/oblique, comminuted, and fracture-dislocation[21]. Another classification was introduced by the AO-group and classifies the proximal ulna and radius fractures into three categories (A)extra-articular, (B)intra-articular fracture of the ulna or the radius, and (C)intra-

articular fractures of both. The AO classification is mainly used as a research tool rather than in clinical practice[6]. The Schatzker and Mayo classification systems[22, 23] are used more widely in the literature and clinical practice as they have the advantage of guiding treatment and useful in predicting outcomes with Schatzker Types C and D and Mayo Type 3 associated with worse outcomes[24-26]. The Mayo classification system is based on fracture displacement, fragmentation , and elbow stability[25]. This classification is simple and is particularly useful in guiding management and has shown to have better inter/intra-observer reproducibility than Colton and Schatzker classifications. For these reasons it is the classification of choice in our practice and will be used during this review[20].

Etiology

The incidence of olecranon fractures is 12 per 100,000 population[1]. The largest epidemiological studies were published from Italy, Scotland, and Sweden with the study from the Swedish Fracture Registry having the largest cohort of 2462 olecranon fracutres[1, 27, 28]. All studies show that a displaced mid-olecranon (Mayo 2) injuries are the most common and accounts for 71-90% of olecranon fractures with the simple configuration (Mayo 2A) being most common. The mean/median age of patients in those studies ranged from 57 to 66, however, there was a significant difference in age between male and female sex. Men are more likely to have an olecranon fracture in the 5th and 6th decade of age and women in the 7th decade. Those three studies show that low energy injury is the most common mechanism of injury and accounts for approximately 70% of all olecranon fractures. High energy injuries are less common and are more likely to occur in younger male patients.

Diagnosis:

Patients typically present following a traumatic event with pain, ecchymosis, and swelling. Clinical examination can demonstrate a palpable gap and/or inability to actively extend the elbow against gravity in displaced fractures indicating a discontinuity of the triceps mechanism. It is essential to examine the entire limb for other injuries, examine for signs of open injury, and complete a neurovascular examination of the extremity.

The diagnosis of isolated olecranon fractures is made by adequate anteroposterior and lateral radiographs. The lateral radiograph has a key role in assessing the displacement, fracture fragmentation, and the presence of joint subluxation. It is important to ensure a true lateral radiograph of the elbow is obtained and that the **center** of the radial neck is aligned with the **center** of the radial head. Identification of the anterior "V" sign is important as this suggests incongruity between the coronoid and trochlea and/or radial head and capitellum and therefore anterior translation of the forearm (Figure 2), indicating a Mayo Type 3 injury. If there is a suspicion of a more complex injury such as fracture-dislocation of the elbow, then we advocate the use of Computed Tomography (CT) to assess the integrity of the coronoid, radial head, and distal humerus[29]. Radiographs and CT are static modalities and if there is any suspicion of ulnohumeral joint instability (Mayo 3 vs Mayo 2) **then this should be examined intra-operatively by applying anterior and posterior force on the forearm to assess for ulnohumeral stability.** If the decision is to manage the patient non-operatively then a close follow-up with serial radiographs is essential as anterior radio-ulna "escape" can occur.

Management

Treatment of an isolated olecranon fractures is based on the fracture and patient characteristics. The treatment is broadly categorized into non-operative and surgical

management. Recommendations for care are listed in table 1 and figure 3 shows the management algorithm followed by the senior author.

Non-operative management

Non-operative management is indicated for most patients with undisplaced fractures (defined as a fracture gap ≤ 2mm)[5, 7]. Recent evidence evaluating non-operative methods shows good outcomes in managing displaced fractures in the elderly with lower functional demands. Most published studies are retrospective observational studies. There is one prospective and one randomized control trial (RCT)[9-11, 30-33]. All these studies included stable fractures only (Mayo 1/2) as it is not desirable to leave a patient with an unstable elbow (Mayo 3) that is likely to lead to substantial disability. A trial by Duckworth et al. was designed to compare the outcomes of displaced olecranon fractures between operative and non-operative management in patients aged ≥75. The study recruited 19 patients and stopped during the recruitment phase due to high complication rates in the surgical arm. Nine-patients (82%) developed a complication in the surgical arm with loss of reduction being the most common in 6 patients (55%). The analysis of those 19 patients showed no difference (although the study lacked power due to the small numbers) in the functional outcomes between the operative and non-operative patients at 6, 12, 26, and 52 weeks with final Mayo Elbow Performance Score (MEPS) of 95 in both groups and Disabilities of Arm, Shoulder and Hand (DASH) score of 23 in the non-operative arm compared to 22 in the operative arm[10]. One meta-analysis published in 2021 compared operative to non-operative management of displaced olecranon fractures in the elderly included the one RCT and 5 observational studies[8]. This study showed an expected finding that fracture union rate was only 14% with non-operative management compared to 95% of the operative group. This, however, did not

appear to impact the functional outcomes with both groups showing good to excellent outcomes with average MEPS of 95 and DASH of 12 in the non-operative group compared to MEPS of 92-95 and DASH of 18-27 in the operative group[8]. The main finding from the meta-analysis was the high re-operation rates associated with surgery which ranged from 33-40% and other complications including wound problems, and infection[8]. Another retrospective cohort-study showed good functional outcomes (MEPS 93 and DASH 26) associated with non-operative management with no difference compared to surgery and reported one complication in the non-operative group of ulnar nerve palsy without requiring further surgery[30]. Bruinsma et al. evaluated 10 patients with non-union of olecranon fractures and reported that patients had reasonable outcomes with only two patients, aged 21 and 45 years, going on to have surgery for non-union[34]. There are two on-going multicentered RCTs comparing operative and non-operative treatment of olecranon fractures, SOFIE and SCORE, from Australia and Scandinavian countries in the recruitment phase[35, 36]. Those trials are likely to strengthen the quality of evidence in the management of elderly patients with displaced olecranon fractures.

There is no evidence to guide what is the best non-operative regime. The method and the period of immobilization differed between studies. We would recommend early range of motion as pain allows, with early check radiographs to ensure there is no evidence of an occult unstable injury pattern.

Operative management:

Surgical fixation of the olecranon reports back to 1883 by Lister[37]. Several surgical methods for osteosynthesis are available including Tension Band Wiring (TBW), Plate Osteosynthesis (PO), Suture Repair (SR), Intramedullary (IM) fixation, and fragment excision with triceps advancement. **In the senior author's practice, SR is used for simple fractures with a**

stable ulnohumeral joint and for multifragmentary fractures we use PO fixation with or

without SR augmentation.

Tension Band Wire

TBW technique is advocated for a nonfragmentary fractures with a stable elbow. It works on

the principle that the bending moment of the forearm created by the triceps contraction

resulting in a dynamic compression across the fracture site. Cadaveric studies disputed if this

principle works and one study showed that the tension principle only works during active

elbow extension between 20°-120°, this means that TBW construct works as a simple

neutralization method for majority of the time (flexion or passive extension)[38]. Several

different TBW constructs have been described in the literature, the most common used

construct is the AO-technique which includes two 1.6mm bicortical K-wires in combination

with 18-gauge stainless steel wire to provide tension in a figure-of-eight configuration (AO-

TBW). Transcortical wires which are subchondral and exit through the volar cortex provide

a more stable construct and lower risk of k-wire migration than intramedullary K-wire

placement but if left long can be responsible for neurological injury, radius impingement, or

even synostosis[39-41]. An alternative technique uses an antegrade partially-threaded cancellous

screw with the same figure-of-eight stainless steel wire (S-TBW) and biomechanically S-

TBW is better than AO-TBW in preventing fracture gapping[42]. Clinical studies show 95-

100% union rate using any TBW construct, however, this was associated with complication

rates as high as 85% with the highest two complications being implant prominence and

removal. Ahmed et al., in a quasi-RCT, compared the two commonly used constructs, with

15 patients in each group, showing no significant difference in the functional outcomes. The

results from this study, however, showed higher rate of implant prominence and removal

surgery associated with AO-TBW. Other modifications have been described including the use

of pins with eyelets (instead of bending the k-wires), two screws, cable-pin TBW, and biodegradable-wire-and-screw TBW. There is one small size RCT published for each construct comparing it with AO-TBW. The results are promising in those studies, but the lack of further studies means the evidence is non-conclusive regarding their effectiveness and safety (Table 2) (Appendix 1)[10, 43-48].

TBW using k-wires was thought to be a simple, reproducible procedure, however, this was challenged by Schneider et al who evaluated the X-rays of 233 patients and rated the fixation by expert elbow trauma surgeons based on 10 key elements and showed a mean of 4.24 errors in each procedure[49]. This study clearly demonstrated that TBW procedure is challenging to reproduce, which might explain the high complications rates.

Plate Osteosynthesis

PO is a common method of fixation in olecranon fractures. It can be used for all subtypes, however, it is also associated with complications and higher operative cost[50]. **The main two indications of using PO are multi-fragmentary fractures or ulnohumeral instability, and it can also be used for simple fracture patterns.** In all olecranon fracture fixation ulnohumeral stability should be assessed with anteroposterior draw and PO is required where instability is detected (Figure 4). In unstable fractures and those with an anterior "V" sign, care must be taken to reduce the forearm dorsally before plate fixation ensuring that all four facets of the greater sigmoid notch are apposed to the trochlea (Figure 5).

Several PO constructs are being used and can be classified by the screw technology used into locking or non-locking plates or based on the number of plates used into single-dorsal or dual-plating (DP). DP uses lower profile plates in an attempt to reduce the irritation caused by the plate. Biomechanical studies show that all PO constructs results in adequate stability to permit early postoperative ROM. Those studies suggested that risk of failure is higher with

osteoporotic bone and when the fracture is proximal to the midpoint of sigmoid notch. The use of 2 proximal triceps screws and augmentation with SR or TBW might be beneficial in more proximal fractures (Figure 6)[51-62]. Clinical studies, compromising largely of retrospective case-series (level-IV), examining PO in different types of olecranon fractures suggest good outcomes associated with use of PO in all fracture types including multifragmentary and unstable injuries. PO has a high union rate (93-100%) and high functional outcomes with an average Oxford Elbow Score of 44, MEPS range 89-99, ROM range 116°-139°, quick-DASH range 13-17, DASH range 4.6-17, and Broberg-Morrey range 81-97. The implant removal in these studies ranged from 11-80%[63-71]. In a study of 321 olecranon fractures fixed with pre-contoured PO, 15.6% patients underwent implant removal[72]. This study has shown that re-operations occur more in young patients and in more complex fractures including Mayo Type-3 and Monteggia like fractures[47, 72-74]. Two comparative studies compared different types of PO and showed comparative functional outcomes and re-operations regardless of the type of plate used[30, 75-78].

Tension Band Wire versus Plate Osteosynthesis:

Both TBW and PO remain the most performed procedures worldwide. Level II-III evidence show both techniques have high union rate and good outcomes, however, they are associated with complications and high re-operation rates[79, 80]. Biomechanical studies show no difference between TBW and PO in fracture displacement with transverse olecranon fractures, however, PO provides better compression at the fracture site, particularly the articular surface[81, 82]. The largest RCT to compare TBW and PO has evaluated their use in simple displaced (Mayo 2A) fractures and shown no difference in the functional outcomes and ROM[44]. TBW was associated with higher risk of complications due to the higher risk of implant removal. More important complications including revision surgery and infection only

occurred in the PO group, however, this did not reach statistical significance (Table 2). Two recent meta-analyses have been published comparing the outcomes of TBW to PO[83, 84]. Koziarz et al. was marked as level II evidence because it had 3 RCTs and numerous observational studies with dramatic effects[84]. Ren et al was ranked as level III evidence because it had only 1 RCT with small sample size and was predominately a review of level III evidence[83]. Both meta-analyses show the outcomes from TBW and PO are satisfactory with no significant difference in the functional outcomes and flexion/extension and pronation/supinations ROM. They also show that TBW is associated with higher re-operation and complications rates. This finding is not present in all studies and two large retrospective cohort-studies showed no significant difference in re-operation rates between PO, TBW and IM fixation methods[41, 85].

It is important to highlight that the evidence in the literature mainly supports using PO in the management of multifragmentary and unstable olecranon process fractures with good outcomes.

Suture repair:

SR methods have been introduced more recently to address the high risk of implant prominence and removal associated with TBW and PO. Five techniques have been discussed in the literature with three techniques using anchor fixation and two use all-suture method[86-89]. The all-suture technique may have economic advantage by not using any anchors. Biomechanical studies show that SR is not inferior to TBW during cyclical load and ultimate fixation strength[90-94]. Clinical studies also show promising results with high union and low complication rates, however, these studies are limited to relatively small retrospective observational studies[87, 89, 91, 95, 96]. Only one comparative study compared re-operation rates and radiological findings between SR, TBW and PO. Most patients (78%) in this study had Mayo type 2A fracture, 30 patients had an olecranon osteotomy and 138 had an olecranon fracture. This study showed lower re-operation rate in the SR group that was only statistically significant when compared to TBW. The SR group had two complications after olecranon osteotomy, one radiological non-union not requiring further surgery and one failed fixation. None of the patients had suture irritation[97]. **Currently, there is a multi-centered RCT in the UK comparing SR to TBW called the SOFFT trial.**

Intramedullary fixation

Currently IM methods are categorized into two types, intramedullary screw fixation (IMS) and Intramedullary nailing system (IMN). IMS was popularized by Johnson et al. in 1986 and entail the use of a cancellous bone screw[98]. It was mainly used in nonfragmentary fractures. Cadaveric studies have shown that using IMS alone has a higher risk of fracture displacement compared to TBW supplementation (S-TBW)[99]. The most important technical consideration in this procedure is to ensure the screw entry point and insertion is along the axis of the ulna medullary canal. The surgeon must consider the VA, described in the anatomy section[100]. If

the entry point is away from the axis, then there is a higher risk of losing reduction during screw insertion. Most studies assessing the outcomes of IMS are retrospective series with a very small sample size and were published before 1990[98]. In the last 30 years we can only find one retrospective case-series of 15 patients to evaluate the outcomes of IMS showing a union rate of 93%, a flexion/extension arc of 134° and a DASH score of 16[101]. The only comparative study comparing IMS to TBW show a significantly higher risk of fracture displacement associated with the IMS[99].

IMN is an alternative technique which has the advantage of not having a protruding hardware (unlike the screw head) and a locking construct that can be used for interfragmentary fractures. Several types of nails have been discussed in the literature including intermedullary olecranon nail (ION), Olecranon osteotomy nail (OIeON), OlecraNail and the XS-Nail. Biomechanical studies have shown the IMN systems to be significantly stronger, stiffer, more stable and have lower risk of loosening than TBW and have shown to have less micromotion than PO[102-104]. Retrospective analysis of the XS-nail shows good outcomes with one study showing an average MEPS of 92 and DASH score of 21 and another study reported the Murphy score in 73 patients, with 68 (93%) having good to excellent outcomes[105, 106]. One study has examined outcomes following OIeON nail in 7 patients with olecranon fractures and all patients achieved union and MEPS score of 100. In the same study 14 patients had olecranon osteotomy and there was one patient with delayed union and implant failure and 3 patients with heterotopic ossification[107].

Fragment excision and triceps advancement.

Fragment excision and repair of the triceps was first described in 1918 by Follie. Since then, several reports supported the use of this procedure mainly as a primary treatment for

displaced olecranon fractures in the elderly[37]. The proportion of olecranon that can excised safely without causing elbow instability has been debated in the literature and ranged between 50-80%, however, a detailed anatomical study by An et al concluded that excision of >50% of the olecranon can lead to defunction of the elbow static stabilizers leading to instability[21, 108]. Other than instability, fragment excision causes elevated joint stresses, the clinical impact of this is not understood[109]. Clinical outcomes of this procedure are historic, and the 'most recent' paper was published in 1993 evaluated the outcomes of 12 patients using Murphy's outcomes scores and reported 11 patients to have good to excellent outcomes and no reoperations. In 1981, Gartsman et al. compared the outcomes of surgical fixation to fragment excision and showed no difference in the elbow extensor performance and lower re-operation rates associated with excision procedure. This procedure may still have a role in salvage situations.

Summary:

The literature evaluating the management of olecranon fractures consists mainly of level III and level IV studies. There are 5 low-quality and 2 moderate-quality RCTs with a small sample size published in this field and 3 Meta-Analysis of largely low-quality studies. The current literature suggest that non-operative management is appropriate for non-displaced fractures (Mayo 1) and displaced stable fractures in the elderly (Mayo 2). Simple displaced fracture (Mayo 2A) can be managed with PO or TBW, however, patients need be counselled about the high risk of complications and re-operation rates. **The outcomes of SR are promising but need an evaluation in a large prospective trial.** The limited evidence also shows good outcomes associated with PO in managing multifragmentary fractures and fractures in an unstable elbow (Mayo 2B and 3).

References:

1.   Duckworth AD, Clement ND, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of fractures of the proximal ulna. Injury. 2012 Mar;43(3):343-6. Epub 20111109.

2.   Siebenlist S, Buchholz A, Braun KF. Fractures of the proximal ulna: current concepts in surgical management. EFORT Open Rev. 2019 Jan;4(1):1-9. Epub 20190107.

3.   Baecher N, Edwards S. Olecranon fractures. Journal of Hand Surgery. 2013;38(3):593-604.

4.   Hak DJ, Golladay GJ. Olecranon fractures: treatment options. The Journal of the American Academy of Orthopaedic Surgeons. 2000;8(4):266-75.

5.   Newman SDS, Mauffrey C, Krikler S. Olecranon fractures. Injury. 2009;40(6):575-81.

6.   Powell AJ, Farhan-Alanie OM, Bryceland JK, Nunn T. The treatment of olecranon fractures in adults. Musculoskeletal surgery. 2017;101(1):1-9.

7.   Veillette CJH, Steinmann SP. Olecranon Fractures. Orthopedic Clinics of North America. 2008;39(2):229-36.

8.   Chen MJ, Campbell ST, Finlay AK, Duckworth AD, Bishop JA, Gardner MJ. Surgical and Nonoperative Management of Olecranon Fractures in the Elderly: A Systematic Review and Meta-Analysis. Journal of orthopaedic trauma. 2021;35(1):10-6.

9.   Duckworth AD, Bugler KE, Clement ND, Court-Brown CM, McQueen MM. Nonoperative management of displaced olecranon fractures in low-demand elderly patients. Journal of Bone and Joint Surgery. 2014;96(1):67-72.

10.   Duckworth AD, Clement ND, McEachan JE, White TO, Court-Brown CM, McQueen MM. Prospective randomised trial of non-operative versus operative management of olecranon fractures in the elderly. Bone Joint J. 2017 Jul;99-b(7):964-72.

11.   Gallucci GL, Piuzzi NS, Slullitel PAI, Boretto JG, Alfie VA, Donndorff A, et al. Non-surgical functional treatment for displaced olecranon fractures in the elderly. Bone and Joint Journal. 2014;96 B(4):530-4.

12.   Beser CG, Demiryurek D, Ozsoy H, Ercakmak B, Hayran M, Kizilay O, et al. Redefining the proximal ulna anatomy. Surgical and Radiologic Anatomy. 2014;36(10):1023-31.

13.   Chapleau J, Balg F, Harvey EJ, Menard J, Vauclair F, Laflamme GY, et al. Impact of olecranon fracture malunion: Study on the importance of PUDA (Proximal Ulna Dorsal Angulation). Injury. 2016;47(11):2520-4.

14.   Potter G, Mascarenhas D, Sciadini M, Carlini A, O'Toole R, Pensy R. What Is the Ideal Starting Point for an Olecranon Screw? An Anatomic Cadaveric Study. J Orthop Trauma. 2018;32(6):313-9.

15.   Rouleau DM, Faber KJ, Athwal GS. The proximal ulna dorsal angulation: a radiographic study. J Shoulder Elbow Surg. 2010 Jan;19(1):26-30.

16.   Shi X, Pan T, Wu D, Chen R, Lin Z, Pan J. The impact of varus angulation on proximal fractures of the ulna. BMC Musculoskelet Disord. 2018 Apr 4;19(1):103. Epub 20180404.

17.   Wegmann S, Rausch V, Hackl M, Leschinger T, Scaal M, Muller LP, et al. Anatomic evaluation of the triceps tendon insertion at the proximal olecranon regarding placement of fracture fixation devices. Surgical and Radiologic Anatomy. 2022;44(4):627-34.

18.   Amis AA, Miller JH. The mechanisms of elbow fractures: an investigation using impact tests in vitro. Injury. 1995 Apr;26(3):163-8.

19.   Greif DN, Emerson CP, Allegra P, Shallop BJ, Kaplan LD. Olecranon Stress Fracture. Clinics in Sports Medicine. 2020;39(3):575-88.

20.   Tamaoki MJ, Matsunaga FT, Silveira JD, Balbachevsky D, Matsumoto MH, Belloti JC. Reproducibility of classifications for olecranon fractures. Injury. 2014 Nov;45 Suppl 5:S18-20.

21.   Colton CL. Fractures of the olecranon in adults: classification and management. Injury. 1973 Nov;5(2):121-9.

22.   Beaudouin E, Augustin B. Is Surgery Needed for Displaced Olecranon Fractures in Patients Aged 75 Years or Over? Orthopaedics & traumatology, surgery & research : OTSR. 2021:103089.

23.   Abdelmalek A, Crowther M. Olecranon fractures in the elderly during the COVID-19 pandemic: Is non-operative treatment reasonable? Review of the current evidence. Musculoskelet Surg. 2021 Aug;105(2):125-30. Epub 20210129.

24.   Rommens PM, Küchle R, Schneider RU, Reuter M. Olecranon fractures in adults: factors influencing outcome. Injury. 2004 Nov;35(11):1149-57.

25.   Morrey BF. Current concepts in the treatment of fractures of the radial head, the olecranon, and the coronoid. Instr Course Lect. 1995;44:175-85.

26.   Schatzker J, Tile M. Fractures of the olecranon. The Rationale of Operative Fracture Care. 3rd ed. Berlin: Springer; 1987. p. p89–95.

27.   Bruggemann A, Mukka S, Wolf O. Epidemiology, classification and treatment of olecranon fractures in adults: an observational study on 2462 fractures from the Swedish Fracture Register. European journal of trauma and emergency surgery : official publication of the European Trauma Society. 2021.

28.   Cantore M, Candela V, Sessa P, Giannicola G, Gumina S. Epidemiology of isolated olecranon fractures: a detailed survey on a large sample of patients in a suburban area. JSES International. 2022;6(2):309-14.

29.   Hamoodi Z, Singh J, Elvey MH, Watts AC. Reliability and validity of the Wrightington classification of elbow fracture-dislocation. Bone Joint J. 2020 Aug;102-b(8):1041-7.

30.   Kaiser P, Stock K, Benedikt S, Kastenberger T, Schmidle G, Arora R. Retrospective comparison of conservative treatment and surgery for widely displaced olecranon fractures in low-demanding geriatric patients. Archives of Orthopaedic and Trauma Surgery. 2021.

31.   Marot V, Bayle-Iniguez X, Cavaignac E, Bonnevialle N, Mansat P, Murgier J. Results of non-operative treatment of olecranon fracture in over 75-year-olds. Orthopaedics and Traumatology: Surgery and Research. 2018;104(1):79-82.

32.   Veras Del Monte L, Sirera Vercher M, Busquets Net R, Castellanos Robles J, Carrera Calderer L, Mir Bullo X. Conservative treatment of displaced fractures of the olecranon in the elderly. Injury. 1999 Mar;30(2):105-10.

33.   J. Batten T, Patel NG, Birdsall P. Olecranon fractures: is nonoperative treatment acceptable in older patients? Current Orthopaedic Practice. 2016;27(1):103-6.

34.   Bruinsma W, Lindenhovius A, McKee M, Athwal G, Ring D. Non-union of non-operatively treated displaced olecranon fractures. Shoulder Elbow. 2012;4(4):273-6.

35.   Symes M, Harris IA, Limbers J, Joshi M. SOFIE: Surgery for Olecranon Fractures in the Elderly: A randomised controlled trial of operative versus non-operative treatment Orthopedics and biomechanics. BMC Musculoskeletal Disorders. 2015;16(1):324.

36.   Rantalaiho I, Laaksonen I, Launonen AP, Luokkala T, Flinkkilä T, Salmela M, et al. Scandinavian Olecranon Research in the Elderly (SCORE): protocol for a non-inferiority, randomised, controlled, multicentre trial comparing operative and conservative treatment of olecranon fractures in the elderly. BMJ Open. 2022;12(1):e055097.

37.   Inhofe P, Howard T. THE TREATMENT OF OLECRANON FRACTURES BY EXCISION OF FRAGMENTS AND REPAIR OF THE EXTENSOR MECHANISM: HISTORICAL REVIEW AND REPORT OF 12 FRACTURES. 1993;16(12):1313-7.

38.   Brink PRG, Windolf M, De Boer P, Brianza S, Braunstein V, Schwieger K. Tension band wiring of the olecranon: Is it really a dynamic principle of osteosynthesis? Injury. 2013;44(4):518-22.

39.   Wang W, Wu G, Shen F, Zhang Y, Liu X. A biomechanical experiment and clinical study of the use of figure of eight plus circular wiring fixation for the treatment of olecranon fractures. Experimental and Therapeutic Medicine. 2012;4(6):1081-6.

40.   Saeed ZM, Trickett RW, Yewlett AD, Matthews TJW. Factors influencing K-wire migration in tension-band wiring of olecranon fractures. Journal of Shoulder and Elbow Surgery. 2014;23(8):1181-6.

41.   Rantalaiho IK, Laaksonen IE, Ryosa AJ, Perkonoja K, Isotalo KJ, Aarimaa VO. Complications and reoperations related to tension band wiring and plate osteosynthesis of olecranon fractures. Journal of Shoulder and Elbow Surgery. 2021;30(10):2412-7.

42.   Hutchinson DT, Horwitz DS, Ha G, Thomas CW, Bachus KN. Cyclic loading of olecranon fracture fixation constructs. J Bone Joint Surg Am. 2003 May;85(5):831-7.

43.   Chen X, Liu P, Zhu X, Cao L, Zhang C, Su J. Design and application of nickel-titanium olecranon memory connector in treatment of olecranon fractures: a prospective randomized controlled trial. Int Orthop. 2013 Jun;37(6):1099-105. Epub 20130418.

44.   Duckworth AD, Clement ND, White TO, Court-Brown CM, McQueen MM. Plate Versus Tension-Band Wire Fixation for Olecranon Fractures. Journal of Bone and Joint Surgery - American Volume. 2017;99(15):1261-73.

45.   Hume MC, Wiss DA. Olecranon fractures. A clinical and radiographic comparison of tension band wiring and plate fixation. Clin Orthop Relat Res. 1992 Dec(285):229-35.

46.   Juutilainen T, Patiälä H, Rokkanen P, Törmälä P. Biodegradable wire fixation in olecranon and patella fractures combined with biodegradable screws or plugs and compared with metallic fixation. Archives of Orthopaedic and Trauma Surgery. 1995 1995/11/01;114(6):319-23.

47.   Liu QH, Fu ZG, Zhou JL, Lu T, Liu T, Shan L, et al. Randomized prospective study of olecranon fracture fixation: Cable pin system versus tension band wiring. Journal of International Medical Research. 2012;40(3):1055-6.

48.   Lu Q, Tang G, Zhao X, Zhang W, Guo S, Wang H. Tension band wiring through double-cannulated screws as a new internal fixation method for treatment of olecranon fractures: a randomized comparative study. Acta orthopaedica et traumatologica turcica. 2015;49(6):654-60.

49.   Schneider MM, Nowak TE, Bastian L, Katthagen JC, Isenberg J, Rommens PM, et al. Tension band wiring in olecranon fractures: The myth of technical simplicity and osteosynthetical perfection. International Orthopaedics. 2014;38(4):847-55.

50.   Steadman JN, Stephens AR, Zhang C, Presson AP, Kazmers NH. Cost Assessment of Plating Versus Tension Band Wiring Constructs for Treating Mayo Type 2A Olecranon Fractures. Journal of Hand Surgery. 2022;47(4):311-9.

51.   Boden AL, Daly CA, Dalwadi PP, Boden SA, Hutton WC, Muppavarapu RC, et al. Biomechanical Evaluation of Standard Versus Extended Proximal Fixation Olecranon Plates for Fixation of Olecranon Fractures. Hand (New York, NY). 2019;14(4):554-9.

52.   Buijze GA, Blankevoort L, Tuijthof GJM, Sierevelt IN, Kloen P. Biomechanical evaluation of fixation of comminuted olecranon fractures: One-third tubular versus locking compression plating. Archives of Orthopaedic and Trauma Surgery. 2010;130(4):459-64.

53.   Edwards SG, Martin BD, Fu RH, Gill JM, Nezhad MK, Orr JA, et al. Comparison of olecranon plate fixation in osteoporotic bone: Do current technologies and designs make a difference? Journal of Orthopaedic Trauma. 2011;25(5):306-11.

54.   Fantry A, Sobel A, Capito N, Hodax JD, Pidgeon T, Koruprolu S, et al. Biomechanical Assessment of Locking Plate Fixation of Comminuted Proximal Olecranon Fractures. Journal of Orthopaedic Trauma. 2018;32(11):E445-E50.

55.   Hoelscher-Doht S, Kladny AM, Paul MM, Eden L, Buesse M, Meffert RH. Low-profile double plating versus dorsal LCP in stabilization of the olecranon fractures. Archives of Orthopaedic and Trauma Surgery. 2021;141(2):245-51.

56.   King GJ, Lammens PN, Milne AD, Roth JH, Johnson JA. Plate fixation of comminuted olecranon fractures: an in vitro biomechanical study. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons [et al]. 1996;5(6):437-41.

57.   Lee Y, Cho BW, Kim MB, Lee YH. Biomechanical comparison between double-plate fixation and posterior plate fixation for comminuted olecranon fracture using two triceps screws in synthetic bone model. Medicine (United States). 2022;101(1):E28313.

58.   Mehta S, Chin M, Sanville J, Namdari S, Hast MW. Use of an additional nonlocking screw in olecranon fracture osteosynthesis changes failure mechanism. Orthopedics. 2019;42(1):e74-e80.

59.   Shakir I, Israel H, Cannada LK, Bledsoe G. Biomechanical study of olecranon plate fixation in comminuted osteoporotic fracture model: Locking compression plates versus dynamic compression plates. Current Orthopaedic Practice. 2018;29(2):167-72.

60.   Sobel AD, Babu JM, Blood TD, Paxton ES. Biomechanical Comparison of Dual and Posterior Locking Plates in an Ex Vivo Comminuted Olecranon Fracture Model. Journal of Hand Surgery. 2022.

61.   Wagner FC, Jaeger M, Friebis C, Maier D, Ophoven C, Yilmaz T, et al. Low-profile double plating of unstable osteoporotic olecranon fractures: a biomechanical comparative study. Journal of Shoulder and Elbow Surgery. 2021;30(7):1519-26.

62.   Wagner FC, Konstantinidis L, Hohloch N, Hohloch L, Suedkamp NP, Reising K. Biomechanical evaluation of two innovative locking implants for comminuted olecranon fractures under high-cycle loading conditions. Injury. 2015;46(6):985-9.

63.   Campbell ST, Debaun MR, Goodnough LH, Bishop JA, Gardner MJ. Geriatric olecranon fractures treated with plate fixation have low complication rates. Current Orthopaedic Practice. 2019;30(4):353-5.

64.   Buijze G, Kloen P. Clinical evaluation of locking compression plate fixation for comminuted olecranon fractures. Journal of Bone and Joint Surgery. 2009;91(10):2416-20.

65.   Siebenlist S, Torsiglieri T, Kraus T, Burghardt RD, Stockle U, Lucke M. Comminuted fractures of the proximal ulna - Preliminary results with an anatomically preshaped locking compression plate (LCP) system. Injury. 2010;41(12):1306-11.

66.   Niglis L, Bonnomet F, Schenck B, Brinkert D, Di Marco A, Adam P, et al. Critical analysis of olecranon fracture management by pre-contoured locking plates. Orthopaedics and Traumatology: Surgery and Research. 2015;101(2):201-7.

67.   Erturer RE, Sever C, Sonmez MM, Ozcelik IB, Akman S, Ozturk I. Results of open reduction and plate osteosynthesis in comminuted fracture of the olecranon. J Shoulder Elbow Surg. 2011 Apr;20(3):449-54.

68.   Klug A, Gramlich Y, Buckup J, Wincheringer D, Hoffmann R, Schmidt-Horlohé K. Excellent results and low complication rate for anatomic polyaxial locking plates in comminuted proximal ulna fractures. J Shoulder Elbow Surg. 2018 Dec;27(12):2198-206. Epub 20180710.

69.   Bailey CS, MacDermid J, Patterson SD, King GJW. Outcome of plate fixation of olecranon fractures. Journal of Orthopaedic Trauma. 2001;15(8):542-8.

70.   De Giacomo AF, Tornetta P, Sinicrope BJ, Cronin PK, Althausen PL, Bray TJ, et al. Outcomes after plating of olecranon fractures: A multicenter evaluation. Injury. 2016;47(7):1466-71.

71.   Inui A, Kuroda T, Kurosawa T, Kokubu T, Mifune Y, Nishimoto H, et al. Case Series of Comminuted Olecranon Fracture Treated by Plate Fixation; Do We Have to Remove the Plate? The Kobe journal of medical sciences. 2018;64(3):E115-E8.

72.   Bouchard C, Bornes TD, Silveira A, Hemstock R, Beaupre L, Chan R. Hardware Complications and Reoperations Following Precontoured Plate Fixation of the Olecranon: A Population-based Study. Journal of shoulder and elbow surgery. 2022.

73.   Contreras ES, Lynch DJ, Hatef S, Speeckaert AL, Goyal KS. Risk Factors for Loss of Reduction After Open Reduction and Internal Fixation of Isolated Olecranon Fractures in Adults. Hand (N Y). 2022 Mar 9:15589447221075667. Epub 20220309.

74.   Contreras ES, Lynch DJ, Hatef S, Speeckaert AL, Goyal KS. Risk factors for symptomatic hardware removal after plate fixation of olecranon fractures: A retrospective chart review. Current Orthopaedic Practice. 2021;32(5):474-8.

75.   Caglar C, Akcaalan S, Ozaslan HI, Yagar H, Ugurlu M. Comparison of tension band wiring and plate fixation in Mayo type 2A olecranon fractures. Joint diseases and related surgery. 2021;32(1):85-92.

76.   DelSole EM, Pean CA, Tejwani NC, Egol KA. Outcome after olecranon fracture repair: Does construct type matter? European Journal of Orthopaedic Surgery and Traumatology. 2016;26(2):153-9.

77.   Ellwein A, Lill H, Warnhoff M, Hackl M, Wegmann K, Müller LP, et al. Can low-profile double-plate osteosynthesis for olecranon fractures reduce implant removal? A

retrospective multicenter study. J Shoulder Elbow Surg. 2020 Jun;29(6):1275-81. Epub 20200410.

78. Shimura H, Nimura A, Fujita K, Kaburagi H. Comparison of the efficacy of the tension band wiring with eyelet wire versus anatomical locking plate fixation for the treatment of displaced olecranon fractures. Journal of Orthopaedic Surgery. 2021;29(3).

79. Flinterman HJA, Doornberg JN, Guitton TG, Ring D, Goslings JC, Kloen P. Long-term outcome of displaced, transverse, noncomminuted olecranon fractures. Clinical Orthopaedics and Related Research. 2014;472(6):1955-61.

80. Wood T, Thomas K, Farrokhyar F, Ristevski B, Bhandari M, Petrisor B. A survey of current practices and preferences for internal fixation of displaced olecranon fractures. Canadian journal of surgery Journal canadien de chirurgie. 2015;58(4):250-6.

81. Wilson J, Bajwa A, Kamath V, Rangan A. Biomechanical comparison of interfragmentary compression in transverse fractures of the olecranon. Journal of Bone and Joint Surgery - Series B. 2011;93 B(2):245-50.

82. Midtgaard KS, Soreide E, Brattgjerd JE, Moatshe G, Madsen JE, Flugsrud GB. Biomechanical comparison of tension band wiring and plate fixation with locking screws in transverse olecranon fractures. Journal of Shoulder and Elbow Surgery. 2020;29(6):1242-8.

83. Ren YM, Qiao HY, Wei ZJ, Lin W, Fan BY, Liu J, et al. Efficacy and safety of tension band wiring versus plate fixation in olecranon fractures: a systematic review and meta-analysis. Journal of orthopaedic surgery and research. 2016;11(1):137.

84. Koziarz A, Woolnough T, Oitment C, Nath S, Johal H. Surgical Management for Olecranon Fractures in Adults: A Systematic Review and Meta-analysis. Orthopedics. 2019 Mar 1;42(2):75-82. Epub 20190227.

85.   Meals C, Johnson C, Reitz L, Hannan Z, Mulliken A, N.N OH, et al. Intramedullary Screw Fixation of Olecranon Fractures Reduces the Risk of Early Unplanned Reoperation: A Retrospective Review of 556 Patients. Journal of Orthopaedic Trauma. 2022;36(1):E24-E9.

86.   Assom M, Lollino N, Caranzano F, Rossi R, Castoldi F. Polyester tension-band wiring of olecranon fractures of elderly people: a simple technique. Injury. 2008 Dec;39(12):1474-6. Epub 20080813.

87.   Bateman DK, Barlow JD, VanBeek C, Abboud JA. Suture anchor fixation of displaced olecranon fractures in the elderly: a case series and surgical technique. J Shoulder Elbow Surg. 2015 Jul;24(7):1090-7. Epub 20150401.

88.   Phadnis J, Eves T, Watts AC. Tension suture fixation of olecranon fractures. JBJS Essential Surgical Techniques. 2021;11(2):e20.00042.

89.   Ravenscroft MJ, Phillips N, Mulgrew E, Yasin MN. Suture Anchor Fixation of Olecranon Fractures: A Case Series. Shoulder & Elbow. 2013 2013/04/01;5(2):116-9.

90.   Ernstbrunner L, Rupasinghe HS, Almond M, Jo O, Zbeda RM, Oppy A, et al. A novel all-suture tension band tape fixation technique for simple olecranon fractures versus conventional tension band wire fixation: A comparative biomechanics study. Journal of shoulder and elbow surgery. 2022.

91.   Garcia-Elvira R, Vives-Barquiel MA, Camacho-Carrasco P, Ballesteros-Betancourt JR, Garcia-Tarrino R, Domingo-Trepat A, et al. Olecranon mayo IIA fractures treated with transosseous high strength suture: A series of 29 cases. Injury. 2020;51(Supplement 1):S94-S102.

92.   Carofino BC, Santangelo SA, Kabadi M, Mazzocca AD, Browner BD. Olecranon Fractures Repaired With FiberWire or Metal Wire Tension Banding: A Biomechanical Comparison. Arthroscopy - Journal of Arthroscopic and Related Surgery. 2007;23(9):964-70.

93.   Lalliss S, Branstetter J. The use of three types of suture and stainless steel wire tension banding for the fixation of simulated olecranon fractures: A COMPARISON STUDY IN CADAVER ELBOWS. J Bone Joint Surg Br. 2010;92-B(2):315-9.

94.   Lee HI, Cho JH, Choi JY, Lee SS, Cho ST. Fixation of Transverse Olecranon Fractures by Suture Bridge Method Using Suture Anchor: Biomechanical Comparison with Tension Band Wiring Technique. Journal of hand surgery Asian-Pacific volume. 2021;26(4):563-70.

95.   Cha SM, Shin HD, Lee JW. Application of the suture bridge method to olecranon fractures with a poor soft-tissue envelope around the elbow: Modification of the Cha-Bateman methods for elderly populations. Journal of Shoulder and Elbow Surgery. 2016;25(8):1243-50.

96.   Das AK, Jariwala A, Watts AC. Suture Repair of Simple Transverse Olecranon Fractures and Chevron Olecranon Osteotomy. Techniques in hand & upper extremity surgery. 2016;20(1):1-5.

97.   Phadnis JS, Vaughan A, Luokkala T, Peters J, Watson JJ, Watts A. Comparison of all suture fixation with tension band wiring and plate fixation of the olecranon. Shoulder Elbow. 2020 Dec;12(6):414-21. Epub 20190228.

98.   Johnson RP, Roetker A, Schwab JP. Olecranon fractures treated with AO screw and tension bands. Orthopedics. 1986 Jan;9(1):66-8.

99.   Helm RH, Hornby R, Miller SWM. The complications of surgical treatment of displaced fractures of the olecranon. Injury. 1987;18(1):48-50.

100.   Potter GD, Mascarenhas D, Sciadini MF, Carlini AR, O'Toole RV, Pensy RA. What Is the Ideal Starting Point for an Olecranon Screw? An Anatomic Cadaveric Study. J Orthop Trauma. 2018 Jun;32(6):313-9.

101.   Bosman WMPF, Emmink BL, Bhashyam AR, Houwert RM, Keizer J. Intramedullary screw fixation for simple displaced olecranon fractures. European journal of trauma and emergency surgery : official publication of the European Trauma Society. 2020;46(1):83-9.

102.   Molloy S, Jasper LE, Elliott DS, Brumback RJ, Belkoff SM. Biomechanical evaluation of intramedullary nail versus tension band fixation for transverse olecranon fractures. Journal of Orthopaedic Trauma. 2004;18(3):170-4.

103.   Nowak TE, Mueller LP, Burkhart KJ, Sternstein W, Reuter M, Rommens PM. Dynamic biomechanical analysis of different olecranon fracture fixation devices - Tension band wiring versus two intramedullary nail systems: An in-vitro cadaveric study. Clinical Biomechanics. 2007;22(6):658-64.

104.   Nowak TE, Burkhart KJ, Mueller LP, Mattyasovszky SG, Andres T, Sternstein W, et al. New intramedullary locking nail for olecranon fracture fixation-an in vitro biomechanical comparison with tension band wiring. Journal of Trauma - Injury, Infection and Critical Care. 2010;69(5):E56-E61.

105.   Friedl W, Gehr J. The XS/XXS and XSL compressions nail in the management of olecranon and proximal ulna fractures. Aktuelle Traumatologie. 2003;33(1):20-5.

106.   Hochtl-Lee L, Spalteholz M, Raven TF, Moghaddam A, Friedl W. Long term results of olecranon fractures treated using the XS nail system. Chinese Journal of Traumatology - English Edition. 2022.

107.   Nijs S, Graeler H, Bellemans J. Fixing simple olecranon fractures with the Olecranon Osteotomy Nail (OleON). Operative Orthopadie und Traumatologie. 2011:1-8.

108.   An KN, Morrey BF, Chao EY. The effect of partial removal of proximal ulna on elbow constraint. Clin Orthop Relat Res. 1986 Aug(209):270-9.

109.   Moed BR, Ede DE, Brown TD. Fractures of the olecranon: an in vitro study of elbow joint stresses after tension-band wire fixation versus proximal fracture fragment excision. J Trauma. 2002 Dec;53(6):1088-93.

Figure legends:

Figure 1: Anatomy of the olecranon process 1a) The four facets of the proximal ulna 1b) The hull of a boat out of the water concept

Anterior articular surface AL: anterolateral facet, AM: anteromedial facet, Posterior articular surface PM: posterolateral facet, PM: posteromedial facet. The area in the green is the four facet. The area in the yellow is the non-loadbearing bare area.

Figure 2: Anterior "V" sign

Figure 3: Management algorithm

Figure 4: Failure of osteosynthesis of olecranon fracture with elbow instability (Mayo type 3) using TBW

Figure 5: Plate osteosynthesis with mal-reduction of the four facets of the greater sigmoid notch leading to joint incongruency

Figure 6: Suture augmentation with plate fixation

CME-1 Figure: Failure of osteosynthesis of olecranon fracture with elbow instability (Mayo type 3) using TBW

CME-2 Figure: The Mayo classification of olecranon fractures

CME-3 Figure: Proximal Ulna Dorsal Angulation (PUDA)