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Extra-articular step osteotomy of the olecranon: A biomechanical assessment☆,☆☆

Matthias A. Zumstein [a,*,1], Alexander Bürki [b,1], Anne-Sophie Massy [a], Philippe Zysset [b], Beat K. Moor [a]

[a] Department of Orthopaedic Surgery and Traumatology, University of Bern, Insel Hospital, Switzerland
[b] Institute for Surgical Technology and Biomechanics, University of Berne, Stauffacherstrasse 78, Bern, Switzerland

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ABSTRACT

Background: Trans-olecranon chevron osteotomies (COs) remain the gold standard surgical approach to type C fractures of the distal humerus. This technique is associated with a high complication rate and development of an extra-articular olecranon osteotomy may be advantageous. The aim of this study was to compare the load to failure of COs with extra-articular oblique osteotomies (OOs) as well as modified, extra-articular step osteotomies (SOs).

Methods: These three osteotomies and their subsequent fixation utilizing a standardized tension band wiring technique were tested in 42 composite analog ulnae models at 20° and 70° of flexion. Triceps loading was simulated with a servo hydraulic testing machine. All specimens were isometrically loaded until failure. Kinematic and force data, as well as interfragmentary motion were recorded.

Results: At 70°, CO failed at a mean load of 963 N (SD 104 N), the OO at 1512 N (SD 208 N) and the SO at 1484 N (SD 153 N), ($P < 0.001$). At 20°, CO failed at a mean load of 707 N (SD 104 N) and OO at 1009 N (SD 85 N) ($P = 0.006$). The highest load to failure was observed for the SO, which was 1277 N (SD 172 N). The load to failure of the SO was significantly higher than the CO as well as the OO.

Conclusion: Extra-articular osteotomies showed a significantly higher load to failure in comparison to traditional CO. At near full extension (20° of flexion), this biomechanical advantage was further enhanced by a step-cut modification of the extra-articular oblique osteotomy.

1. Introduction

The management of intra-articular fractures of the distal humerus remains a challenging problem despite considerable improvements in both operative techniques and surgical implants. Reconstruction of the articular block is particularly demanding if there is comminution of the relatively large articular surfaces with its inherently complex geometry. A good functional outcome is dependent on anatomical reduction of the articular surfaces and subsequent healing. The osteosynthesis must be stable enough to permit early range of motion and functional rehabilitation (Holdsworth and Mossad, 1990; John et al., 1994).

A key element in achieving these objectives is adequate surgical exposure allowing sufficient visualization of the joint surface. Many surgical approaches have been advocated for this purpose, but the transolecranon approach using distal apex chevron osteotomy remains the gold standard for most surgeons in order to maximize exposure (Dakoure et al., 2007; Jupiter et al., 1985; Wilkinson and Stanley, 2001). Alternatively in more simple fractures, a triceps split or paratricipital approach can be used. However, as limited exposure may be an issue with the later techniques, a triceps reflecting approach is an option.

Depending on the method of fixation, a wide range of complications have been reported. Although some have reported union rates of up to 100% (Coles et al., 2006; Ring et al., 2004) with osteotomies, several authors have observed complications with early displacement, delayed unions, non-unions or failures of fixation (Holdsworth and Mossad, 1990; Sane et al., 2009; Sodergard et al., 1992). The major complication of the triceps reflecting approach is its potential to cause triceps insufficiency (Iselin et al., 2014; Muller et al., 2005).

Extra-articular oblique osteotomy of the olecranon may be advantageous, as this technique provides improved distal humeral exposure when compared to a triceps splitting or paratricipital approach, without the potential problems of triceps insufficiency with the triceps reflecting approach. It may also enhance bony contact and therefore union post fixation. A step-cut modification of the extra-articular osteotomy may additionally increase the inherent stability of the construct, as bony interdigitation at the step may neutralize shear forces from triceps contraction. Furthermore, this approach would decrease the risk of intra-

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* Corresponding author at: Department of Orthopaedic Surgery and Traumatology, University of Berne, Insel Hospital, Freiburgstrasse 18, 3010 Bern, Switzerland.
E-mail address: m.zumstein10@gmail.com (M.A. Zumstein).

[1] These two authors contributed equally to the manuscript and share first authorship.

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articular steps in patients with non-anatomic reduction or secondary displacement (Voor et al., 1995).

The aim of this study was to investigate the load to failure of three olecranon osteotomies post fixation with a traditional tension band wiring technique (Mueller et al., 1970; Weber and Vasey, 1963) (Fig. 1):

1. Classical trans-articular chevron osteotomy (CO)
2. Extra-articular oblique osteotomy (OO)
3. Modified extra-articular step osteotomy (SO)

We hypothesized that the "step-cut" modification would substantially increase the load to failure of extra-articular oblique osteotomy.

2. Methods

2.1. Testing specimens

To avoid the structural and geometric inconsistencies inherent to cadaveric specimens, we used composite analog ulna models (Sawbones, Pacific Research Laboratories, Inc., Vashon, WA). These fourth generation bone surrogates demonstrate tensile strength, stiffness, and fracture toughness that are comparable to human cortical bones (Chong et al., 2007). In a recently described technique, synthetic tendons were used to simulate joint loading by the triceps muscle pull (UK 040, ZURRfix AG, 6210 Sursee, Switzerland) (Osterhoff et al., 2011). These were attached at the anatomical footprint of the triceps insertion using instant adhesive (Cyanoacrylate, Loctite 401, Henkel AG & Co. KGaA, Germany) (Keener et al., 2010a). The fixation area for the triceps analog was chosen according to a previously published anatomical investigation by Yeh et al. (2010a,b). The distance from the olecranon tip to the proximal insertion of the triceps was set at 12 mm. We chose a bony footprint length and width of approximately 20 mm and 24 mm, respectively. This point also determined the starting point of the extra-articular osteotomies. The osteotomy position was standardized for each group by a customized cutting technique.

2.1.1. Chevron-shaped osteotomy (CO)

An apex distal chevron osteotomy was performed, using the Heim and Pfeiffer technique (Heim and Peiffer, 1982). This intra-articular osteotomy entered the joint surface at the central portion of the trochlear notch (Fig. 1, CO).

2.1.2. Oblique osteotomy (OO)

This osteotomy was strictly extra-articular, as described by Mueller et al. (1970). As the triceps insertion is on the dorsal and not on the proximal aspect of the proximal ulna, the proximal area was split into three thirds (Keener et al., 2010a; Yeh et al., 2010a,b) The cut was made from the intersection of the dorsal to the middle third of the proximal area of the proximal ulna in a postero-distal direction. The starting point of the osteotomy was chosen 12 mm from the tip of the olecranon. From this point the cut was made in a postero-distal direction in a 20° angle with respect to the posterior cortex of the proximal ulna. (Fig. 1, OO) (Rouleau et al., 2010).

2.1.3. Step-cut osteotomy (SO)

This new technique was a modification of the extra-articular oblique osteotomy, using the same slope and starting point at the proximal edge of the triceps footprint. The oblique cut was augmented with a 2 mm step at the middle third of the osteotomy (Fig. 1, SO). A special cutting guide was developed in order to create these step osteotomies in a standardized fashion (Fig. 2).

All osteotomies were stabilized using an identical standardized tension band wiring technique for each group. Two parallel 1.6 mm Kirschner wires (K wires) were drilled across the osteotomy along the axis of the ulna, each with bicortical purchase (Weber and Vasey, 1963). The wires entered the olecranon 10 mm proximal to its posterior edge and passed through the anterior cortex just distal to the base of the coronoid process. At the same level, a horizontal hole was made in the middle third of the antero-posterior diameter of the ulnar shaft with a 2 mm power drill (Rowland and Burkhart, 1992). A 1.25 mm stainless-steel cerclage wire with a precontoured loop was passed through the distal drill hole. Both limbs were crossed over the dorsal surface of the ulna in a figure-of-8 fashion. The limb without loop was then passed beneath the artificial triceps tendon around the proximal end of the protruding K-wires. The precontoured and the closing loop of the figure-of-8 construct were simultaneously tightened by the same surgeon (A.M.) until the coil started to double back upon itself, as performed clinically.

2.2. Biomechanical testing

Pilot tests using the same experimental set-up as for the main investigation were performed to assess the loading characteristics of the osteotomies at different elbow positions. This preliminary testing revealed excellent loading behavior for all osteotomies with flexion angles beyond 80° (Fig. 3a). At flexion angles greater than 80°, only saw bone failure modes occurred, since the load was not transferred to the osteotomy in this flexion range. Despite loading of up to 1500 N, all specimens failed with a fracture close to the tip of the olecranon process — without relevant opening at the osteotomy site. The reverse was observed in full extension (Fig. 3a). Upon loading, the specimens were pulled in slight hyperextension and all failed by gradual opening of the osteotomies. Due to the slight hyperextension, the resulting force vector did not lead to bony abutment of the step-cut, which explains its identical failure mode at this elbow position.

On the basis of these findings, we focused our investigation on flexion arcs of 20° and 70°. Additionally, we defined two different modes of failure (Fig. 3b):

Firstly, gap formation in the osteotomy of 2 mm, which has been shown to be strongly associated with posttraumatic osteoarthritis (Murphy et al., 1987); and secondly, the occurrence of a fracture of the sawbones.

The investigation was performed on 42 specimens, 7 for each group and position. The specimens were fixed in a custom-designed aluminum holder, allowing maintenance of predefined elbow positions of 20° or 70° flexion (Fig. 4). The joint surface of the artificial bones was

Fig. 1. Illustration of the three assessed osteotomies: the intra-articular chevron-shaped osteotomy (CO), the extra-articular oblique osteotomy (OO) and the modified, extra-articular step-cut osteotomy (SO).