A biomechanical study comparing the mean load to failure of two different osteosynthesis techniques for the Step-Cut Olecranon Osteotomy

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Abstract

Background: A tension band wiring technique is the current gold standard for osteosynthesis of olecranon osteotomies, although the technique has several practical disadvantages and its theoretical advantages have been questioned. The Step-Cut Olecranon osteotomy is an interesting new option for surgeons to access distal intra-articular humerus fractures, but its stability has only been assessed using the tension band wiring osteosynthesis. Therefore, the mean load to failure of this osteotomy with two different osteosynthesis techniques (tension band wiring and compression screws) was assessed. A higher load to failure was hypnotized for the tension-band-wiring osteosynthesis group.

Methods: A Step-Cut Olecranon osteotomy was performed on 32 Sawbones. Half were secured by a tension band wiring and the other half by two compression screws. The humero-ulnar joint was simulated using an established test setup, which allows the application of triceps traction force through a tendon model to the ulna model, while the joint is in a fixed position. Eight models of each group were tested at one of two angles (20° and 70° of flexion) by isometrical loading until failure. A failure was defined as either complete fracture or gap formation of more than 2mm between osteotomy and the remaining model.

Results: At 20° of flexion, the mean load to failure in the tension band wiring group was 1360 N (SD 238) and 1401 N (SD 261) in the compression screw group. At 70° of flexion, it was 1398 N (SD 215) and 1614 N (SD 427), respectively. Differences did not reach significance (p = 0.88 at 20°, p = 0.28 at 70°).

Conclusions: A tension band wiring osteosynthesis does not provide higher stability than a compression screw osteosynthesis for the Step-Cut Olecranon osteotomy. A Step-Cut Olecranon osteotomy with screw osteosynthesis might be an interesting option for surgeons when treating intra-articular distal humeral fractures.

Background

Intra-articular distal humeral fractures are relatively rare but challenging. Today, three approaches are commonly used to expose intra-articular fractures of the distal humerus: olecranon osteotomy, the triceps splitting approach and the paratricipital approach. Each approach has its advantages and disadvantages. However, according to Wilkinson et. al., and Dakouré et. al., olecranon osteotomy provides best exposure of the bony anatomy and is therefore considered as the gold standard for the most often complex intra-articular fracture patterns (1, 2). Various shapes of osteotomy and subsequent osteosynthesis techniques have been proposed to improve stability and decrease complication rates associated with this approach. Recently, our research group presented the Step-Cut Olecranon osteotomy (SCOOT), a modification of the extra-articular oblique olecranon osteotomy (3). The results of this biomechanical study demonstrated enhanced stability of the SCOOT compared to both an oblique olecranon osteotomy and a classic chevron osteotomy. In this first study, a conventional tension band wiring technique was used for osteosynthesis.

Tension band osteosynthesis is accepted as a simple and inexpensive technique with excellent biomechanical properties and low complication rates. However, the results of recent biomechanical and clinical studies questioned this dogma. Several studies reported high rates of complication associated with a tension band construct (4–8). Schneider et al. reviewed 239 cases with olecranon fractures, which were treated using a tension band wiring technique, for operative imperfection using over 2000 X-rays (9). They concluded that the tension band wiring technique may not be as easy or reproducible as surgeons and the literature suggest. Furthermore, Hutchinson et al., Wagner et al. and Wilson et al., all questioned the biomechanical principles and the resulting advantages of the tension band concept (10–12). Hence, we proposed an assessment of an alternative osteosynthesis technique for the SCOOT.

The goal of this study was to compare the load to failure of a SCOOT secured by two compression screws (CS) and a SCOOT secured by the current gold standard (tension-band-wiring technique (TB)). Two compression screws were chosen as an alternative osteosynthesis technique for two reasons: a) the technique might further improve the stability of the SCOOT by enhancing force transmission at the step and b) its simplicity. A higher load to failure for the SOOT with tension-band-wiring technique (TB) was hypothesized because the constructed should convert the tensile forces on the posterior aspect of the olecranon into compression forces at the step side and thus enhance the effect of the step.

Methods

A recently described synthetic bone (Sawbones, Pacific Research Laboratories, Inc., Vashon, WA) and tendon model (UK 040, ZURRfix AG, Sursee, Switzerland) were used with a validated test setup (3, 13, 14). The setup simulated a humero-ulnar joint and allowed the application of triceps traction force through the tendon model to the ulna model, while the joint was in a fixed position. Figure 1 shows the used test setup with a model mounted to it in 70° of flexion in the humero-ulnar joint.

Olecranon Osteotomy

The SCOOT is an adapted version of the extra-articular oblique olecranon osteotomy (3, 15). As the name implies, the difference between the two is a step in the cutting plane. A cutting guide was used to standardize the procedure and generate a 2 mm step in the osteotomy, it is secured to the ulna with Kirschner wires (K-wires) prior to making the osteotomy. Figure 2 shows the cutting guide and the two osteotomy types (oblique olecranon osteotomy and SCOOT). Two serial, parallel saw cuts were made through the guide and the osteotomy was completed with a 2 mm osteotome.

Osteosynthesis Techniques

SCOOT with tension band wiring osteosynthesis (TB)

A figure-of-eight tension wiring, as recommended by the Arbeitsgemeinschaft für Osteosynthesefragen (AO Foundation), was performed (16). First, two 1.6 mm K-wires were inserted bi-cortically through the osteotomy and the ulna. They were placed parallel to the longitudinal axis of the ulna in a 45° angle to the cutting plane, aiming anterior-distal. They entered distal in the proximal ulna between the triceps footprint and the proximal cut of the osteotomy and passed through the anterior cortical at the base of the coronoid process. A hole was drilled, in the middle of the ulna level with the distal cortical penetration of the K-wires. A 1.5 mm stainless steel wire was passed through the hole distally and around the K-wires proximally in a figure-of-eight pattern with two loops for tightening. The loops were twisted simultaneously until the wire blanched in order to reduce and compress the osteotomy.

Scoot Screw Osteosynthesis (cs)

Two 2.5 mm bicortical holes were drilled from the dorsal ulna, perpendicular to the plane of the osteotomy, aiming anterior and distal. One hole was drilled 1 cm distally to the step and the other hole 3 cm distally to the step in the osteotomy. Both screw holes were placed distally to the step to prevent intraarticular placement of the screws and increase the safety of the procedure. Each hole was over-drilled to 3.5 mm in the osteotomy segment to generate a lag screw construct. Two 34 mm fully-threaded cortical screws were inserted and tightened with two fingers by the same person (SH). Figure 3 illustrates a proximal ulna with a step cut osteotomy and a screw osteosynthesis.

Test Angles

The position of the elbow joint strongly influences its loading characteristic (3). At flexion of more than 80°, the tensile forces are absorbed by the entire proximal ulna, leading to unphysiologically fractures when forces became excessive. At full extension, on the other hand, forces are mainly absorbed by the osteosynthesis material of the osteotomy. Unfortunately, at these angles the SCOOT also loses its advantage over the chevron Osteotomy because the vector of the triceps tensile force does not lead to a bony abutment of the step-cut. From a clinical point of view, the highest triceps tensile forces probably develop during a movement between 80° and 20° of flexion, for example when getting up from a chair. Hence, beyond the range of 70° to 20° of flexion no difference between the two groups was expected and clinically the highest forces are expected to occur within the range of 70° to 20° of flexion. Consequently, the models were tested at 20° and 70° of flexion.

Failure Modes

The endpoint “failure” was defined as follow:

1. A complete fracture in the Sawbone model. We anticipated that no movement of the osteotomy fragment would be possible in the models with a screw osteosynthesis and thus a fracture would

occur.

2. A shift of the osteotomy along the K-wires, resulting in a gap between ulna and osteotomized part. A failure was defined as a gap of more than 2 mm because Murphy et al., showed a direct connection between a gap greater than 2 mm gap and the development of posttraumatic osteoarthritis (17)

Statistical Analysis

The statistical analysis was performed using R (64-bit Version 3.4.1.) and GPower (64-bit Version 3.1). An a-prior power analysis was performed to calculate the sample size needed to find a significant difference in mean load to failure between the groups. The estimated effect size was 1.6 based on the data of the first study (difference between groups 200N, standard deviation 125N for both groups) (3). It was decided to work with 8 samples per group, hence 36 samples in total (four groups: CS at 20°, TB at 20°, CS at 70° and TB at 70°). The estimated power and an average effect size of 1.6 was 0.9. Descriptive statistics including means, median and standard deviations are presented. Wilcoxon rank sum test was used to compare the two groups since normal distributions of the data could not be confirmed. The level of statistical significance was set at $P < 0.05$.

Results

Table 1 shows the mean loads to failure of the four different groups and their failure modes.

Table 1
Sample size, mean load to failure (Newton (N)), standard derivation (SD), Median Range and endpoints of each group.

	Sample Size	Mean (N)	SD (N)	Median (N)	Range (N) Max. – Min.	Fracture of the Osteotomy	Fracture of the entire Ulna	Shift
Tension band wiring at 20°	8	1360	239	1385	1624–894	0	6	2
Screw at 20°	8	1401	261	1380	1946–1125	4	4	0
Tension band wiring at 70°	8	1398	216	1368	1826 – 1086	1	5	2
Screw at 70°	7	1613	427	1521	2273–1092	3	3	1

Testing at 20° flexion

The mean load to failure and standard deviation (SD) of the TB group (1360 N SD 238) was not significantly different from the mean failure load of the CS group (1401 N SD 261) ($p = 0.88$). All CS models failed due to a fracture. In half of the CS models the osteotomized part fractured, while in the other half the entire proximal ulna fractured. Six models of the TB group failed likewise, due to a fracture of the entire proximal ulna. In the remaining two models a gap emerged between osteotomized part and ulna. Figure 4 shows a Box-Whisker-Plot comparing the two groups.

Testing at 70° flexion

The mean load to failure and SD of the TB group (1398 N SD 215) was lower than in the CS group (1614 N SD 427), although the difference did not reach significance ($p = 0.28$). The endpoints in the TB group were the same as during testing at 20°. Two models failed due to a gap formation, while in the rest of the group (n = 6) a fracture of the entire proximal ulna occurred. The majority (n = 6) of the CS group failed due to a fracture. However, there were two exceptions. In one case, the screws were pulled out of the ulna, leading to a gap formation. In the other case, the triceps tendon was torn from the model at a load of 2000N. Since this was not a previously defined endpoint, this sample was excluded from the analysis. Figure 5 shows a Box-Whisker-Plot comparing the two groups.

Discussion

Various research groups analyzed the loading characteristics of different osteosyntheses techniques for olecranon osteotomies (10, 11, 18, 19). A stable osteosynthesis seems best achieved by using either a cancellous screw plus tension band wiring or only tension band wiring. While most studies show slightly higher stability of the cancellous screw with tension band wiring, the exclusive use of tension band wiring seems more common in everyday clinic (9). Plate fixation offers even more stability and several clinical trials reported good results (20, 21). However, plate osteosynthesis is more expensive and hardware removal is frequently required, which must be balanced against the relatively small increase in stability.

The original tension band wiring concept described the conversion of posterior tensile forces to anterior compressive forces. Although this concept is widely accepted and the technique is used in everyday clinic, serval studies have challenged the principles. Hutchinson et al, compared the stability of different osteosynthesis techniques for transverse olecranon osteotomies using cadaveric elbows. They applied cyclic loads and monitored gap formation using displacement transducers. They did not find any compression forces posteriorly on the tension side or anteriorly near the articular surface (10). Wilson et. al, reported similar findings, when investigating interfragmentary compression in transverse olecranon osteotomies secured with tension band wiring technique or plate fixation (12). Wagner et. al. evaluated three different fixation methods of the chevron osteotomy using a Roentgen stereophotogrammetric analysis (RSA) and reported similar results (11). The original tension band theory, therefore, remains a point of contention.

It was hypothesized that SCOOT with the tension wiring osteosynthesis would have a higher load to failure than the SCOOT with screw osteosynthesis. The results of this study reject this hypothesis since there was no significant difference between the groups. However, our study was adequately powered to detect relevant differences and thus the two methods can be considered to have a similar mean load to failures and provide comparable stability in a clinical setting. The endpoint of most of the models (26 out of 31) was an unphysiological fracture. These fractures are most likely caused by a failure of the ulna models rather than an insufficient osteosynthesis. The formation of a gap in 5 cases is interesting since in the previous study all 14 SCOOT models failed due to a fracture (3). However, as one would expect, this endpoint mainly occurred in the TB group (4 out of 5). Hence, a suboptimal interaction between the tension band wiring technique with the SCOOT may explain this gap formation.

In our previous study, the SCOOT was presented and its mean load to failure was compared to two other types of olecranon osteotomies (chevron osteotomy, oblique olecranon osteotomy) (3). In each case tension-band wiring with two bicortical K-wires was used. The results showed a significantly higher mean load to failure of the SCOOT compared to the chevron osteotomy at both angles. Compared to the oblique olecranon osteotomy, the mean failure load was higher, but the difference was only significant at 20° of flexion. Intentionally, the same models and test setup were used for this study. It was therefore possible to perform an additional analysis including the data from the first study. A Wilcoxon Rank Sum Test was used to compare the 4 different groups: TB, CS, Chevron osteotomy, Oblique olecranon osteotomy (p-values were adjusted using Holm's method to account for multiple comparisons). When comparing the loads to failure at 20° of flexion, CS and TB showed significantly higher loads compared to both other osteotomy types (oblique olecranon and chevron osteotomy, both $p < 0.005$). The results of the comparison at 70° flexion were similar, however, the differences between CS and oblique olecranon osteotomy (with tension band wiring) as well as between TB and oblique olecranon osteotomy (with tension band wiring) were not significant ($p = 0.9$). This implied a higher mean load of the SCOOT independent of osteosynthesis technique compared to the chevron and the oblique olecranon osteotomy with tension band wiring.

The study has several limitations. First, the study was performed on a Sawbone model. However, fourth-generation bone surrogates grant constant biomechanical properties which are very similar to the human bone and potential differences are expected to be minimal. Second, our test setup only simulated the triceps force. Some authors would point out the impact of the biceps as well as the brachialis muscle on the humero-ulnar joint. However, the impact of these muscles is likely to be limited since they do not attach at the osteotomy site directly. Third, we only simulated isometric muscle contraction and only tested at two angles. Although more extensive testing may be ideal, our method is supported by previous results from our group demonstrating that testing at these two angles is sufficient for biomechanical analysis and almost all existing literature examining olecranon osteotomies and olecranon fractures has tested samples only at one angle (90° of flexion)(3). Our study provides a more comprehensive assessment than previous work, although, validation of the results under cyclic loading and at other angles may be useful.

Despite these limitations, this study provides valuable information regarding the SCOOT. In practice, a SCOOT with screw osteosynthesis should be more resistant to the triceps tension forces than a chevron osteotomy and provide similar stability as an oblique olecranon osteotomy or a SCOOT with tension band wiring. Furthermore, the step of the SCOOT should theoretically result in higher rotational stability in comparison to the oblique olecranon osteotomy. However further studies are necessary to confirm this assumption. From a surgeon's perspective, our results are important as they further support the use of the SCOOT. The first study found the SCOOT with tension band wiring technique provided improved stability compared to chevron and oblique osteotomy (3). A second study found the SCOOT to have a substantially increased (2.6-times) bone contact surface in the area of the osteotomy in comparison to the chevron osteotomy (22). The results of this study suggest that a simple osteosynthesis with two compression screws is sufficient for osteosynthesis of the SCOOT. A simple osteosynthesis technique has several benefits: first, osteosynthesis is much easier to perform, which could potentially lead to shorter surgeries and fewer complications; second, hardware irritations are less likely with this osteosynthesis technique and thus the rate for second interventions for hardware removal should decrease and, if required, screw removal could be performed under local anesthesia.

However further studies investigating the stability of a screw osteosynthesis for the SCOOT in a clinical setting are necessary before our result can gain relevance. Nevertheless, it seems safe to assume that the risk of failure is minimal when using a SCOOT fixed with either screws or tension band construct since the mean loads to failure of all groups were much higher than loads usually occurring during an early postoperative rehabilitation (23).

Conclusion

A tension band wiring osteosynthesis does not provide higher stability than a compression screw osteosynthesis for the Step-Cut Olecranon osteotomy. A Step-Cut Olecranon osteotomy with screw osteosynthesis might be an interesting option for surgeons when treating intra-articular distal humeral fractures.

Abbreviations

K-wires Kirschner wires

SCOOT Step-Cut Olecranon osteotomy

SD Standard deviation

CS Step-Cut Olecranon osteotomy with two compression screws

TB Step-Cut Olecranon osteotomy with tension-band-wiring technique

RSA Roentgen stereophotogrammetric analysis

Declarations

Ethics approval: This study did not involve human participants, human data or human tissue and therefore ethics approval was waived.

Consent for publication: Not applicable

Availability of data and material: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interests: The authors declare that they have no competing interests

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Authors' contributions: All authors read and approved the final manuscript.

Conflicts of interest: All authors declare that they have no conflict of interest**.**

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Figures

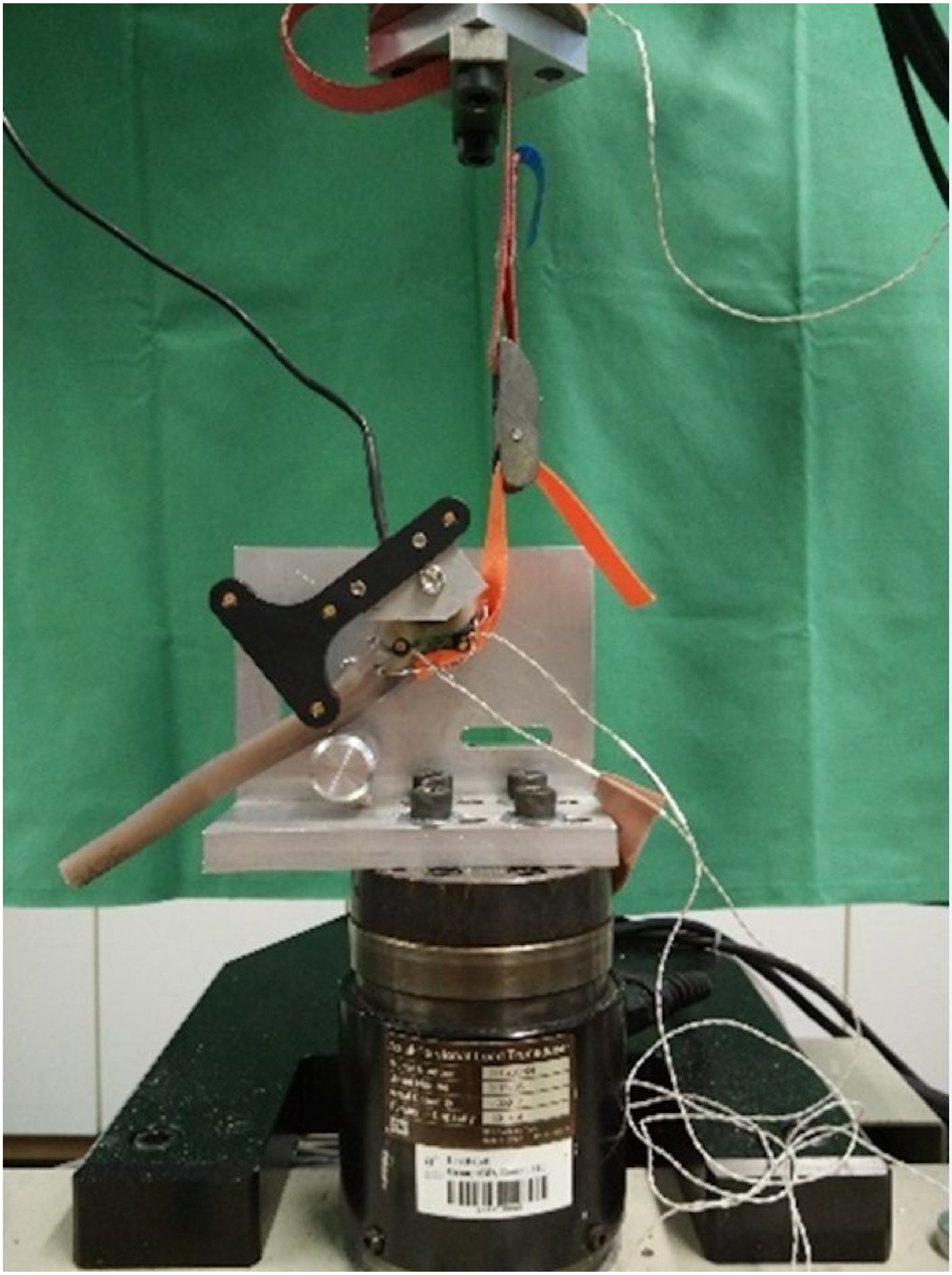

Figure 1

Test step up with ulna model mounted to it an angle of 70° of flexion.

Figure 2

Cutting guide for SCOOT (left) and the SCOOT (right).

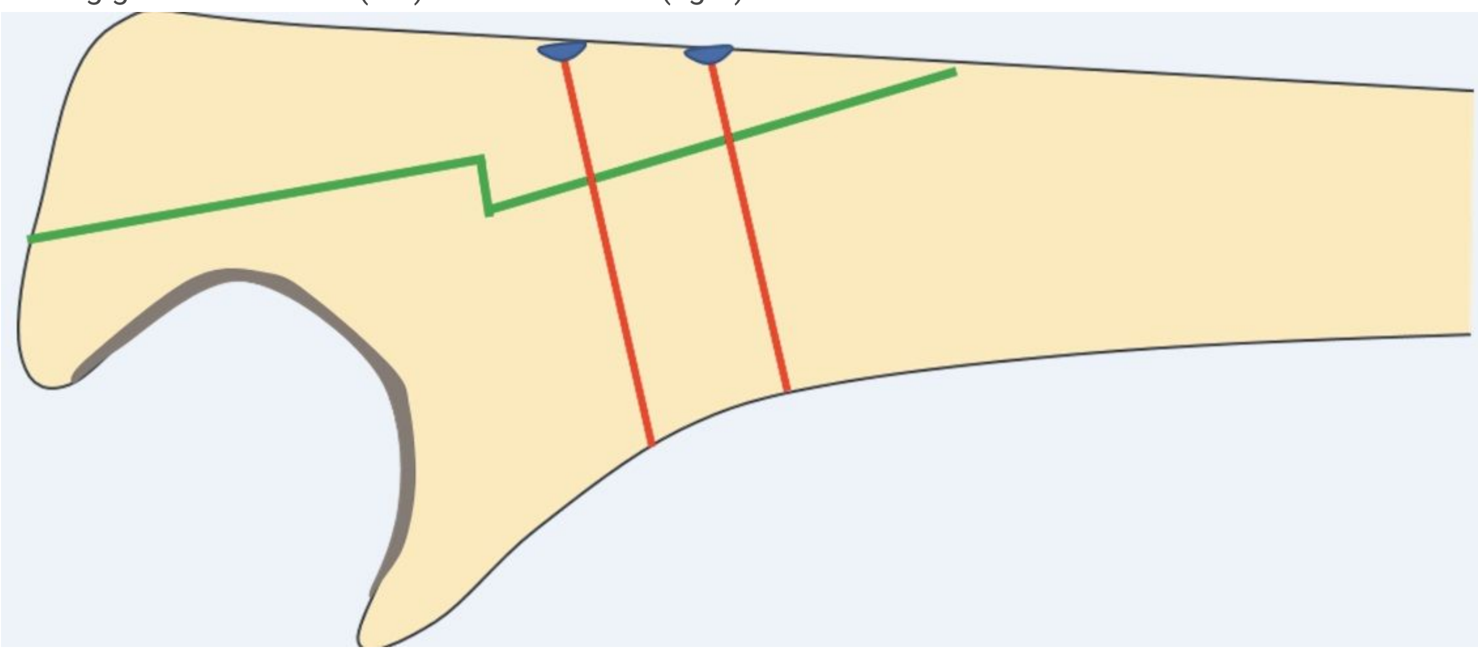

Figure 3

Distal ulna with SCOOT and screw osteosynthesis. The two cortical screws were placed perpendicular to the plane of the osteotomy and anchored in both cortices.

Figure 4

Boxplots of the load to failure of the two groups Step-Cut osteotomy with screw and Step-Cut osteotomy with tension band wiring at 20° flexion.

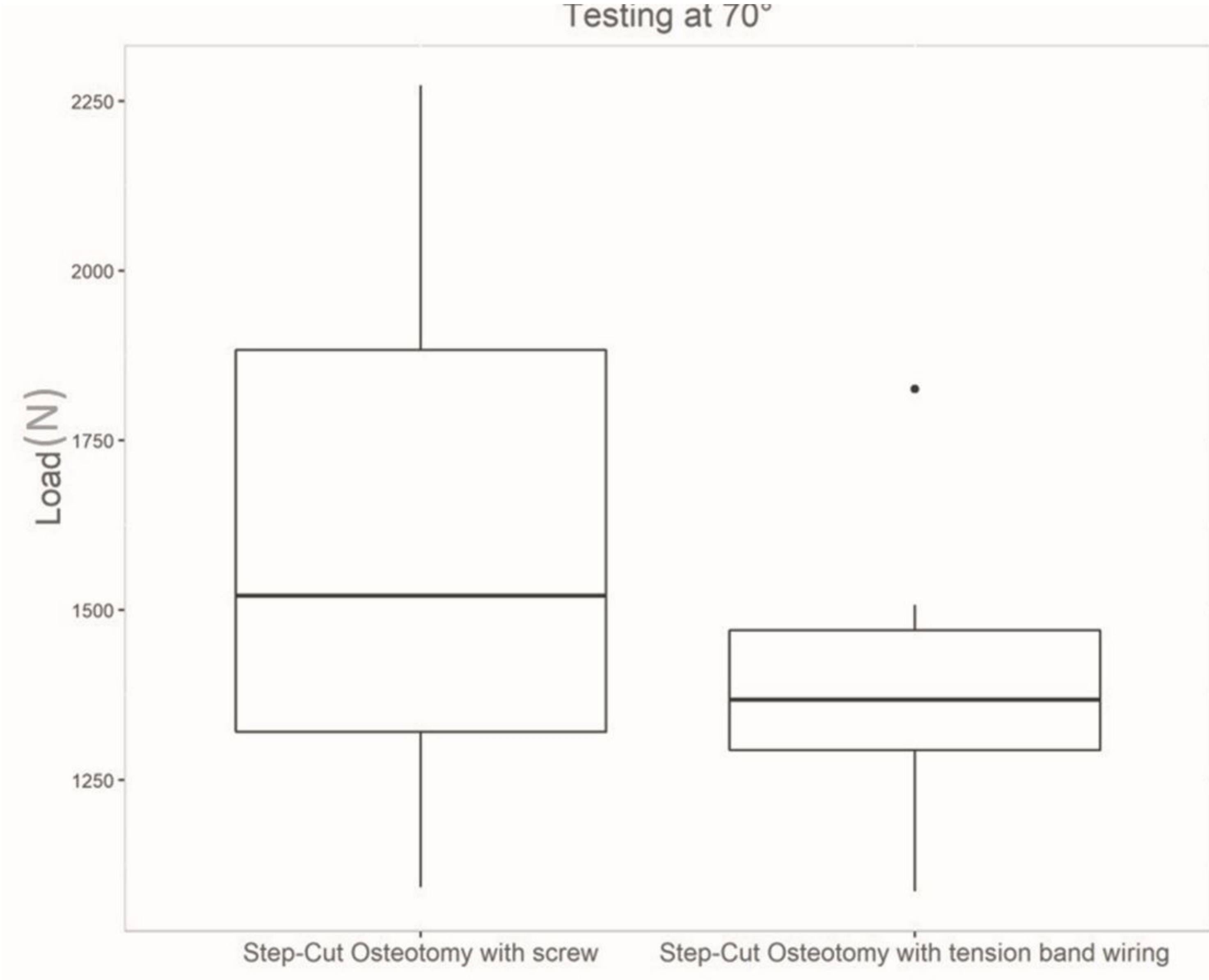

Figure 5

Boxplots of the load to failure of the two groups Step-Cut osteotomy with screw and Step-Cut osteotomy with tension band wiring at 70° flexion.

Supplementary Files

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