Risk Factors for Hardware Related Complications After Olecranon Fracture Fixation

Scholarly Report submitted in partial fulfillment of the MD Degree at Harvard Medical School

Date: 1 March 2020

Student Name: George Bugarinovic, BS

Scholarly Report Title: Risk Factors for Hardware Related Complications after Olecranon Fracture Fixation

Mentor Name(s) and Affiliations: Brandon E. Earp, MD, Chief of Orthopedics, Brigham and Women's Faulkner Hospital; Vice Chair of Clinical Operations, Department of Orthopedic Surgery, Brigham and Women's Hospital

TITLE: Risk Factors for Hardware Related Complications after Olecranon Fracture Fixation

Bugarinovic G, McFarlane KH, Benavent KA, Janssen SJ, Blazar PE & Earp BE.

Purpose: Olecranon fractures are common in adults, and most are treated via surgical intervention. There are two surgical methods most used for open reduction internal fixation (ORIF) of a fractured olecranon: a tension band wire (TB) construct and a locking-plate-and-screw (PS) construct. Both methods provide good functional outcomes, but post-operative complications (symptomatic hardware, nerve irritation, infection, etc.) remain a challenge to patients and surgeons alike.

The aim of this study is to evaluate risk factors for symptomatic hardware and removal of hardware (ROH) after olecranon ORIF and to assess differences between olecranon locking plate and screws (P&S) or tension band (TB) wire cohorts. This chart review will provide surgeons with empirical evidence to help them decide on the appropriate surgical technique for each patient suffering this elbow injury, based on their unique demographics and personal characteristics.

Methods: This is a retrospective cohort study performed at an Academic Level I Trauma Center. The medical records of 331 patients with olecranon fractures treated with ORIF from 2012-2016 were reviewed. After exclusions, 189 patients were included in the study. Patients undergoing ORIF with either P&S or TB fixation were compared. The outcome measures included complications, requirement of removal of hardware (ROH) and subsequent surgery were compared between cohorts.

Results: There were 124 cases in the P&S cohort, and 65 in the TB cohort. The overall reoperation rate was 31.2% (59/189). The overall incidence of ROH for all cases was 29.1% (55/189). Patients who required ROH or developed symptomatic hardware were significantly younger than those who did not (P&S $p<0.003$; TB $p<0.004$). Age and BMI were associated with ROH + symptomatic hardware after P&S fixation. Age (but not BMI) was associated with ROH or symptomatic hardware after TB fixation. Measured hardware prominence was not associated with ROH or ROH + symptomatic hardware for either P&S or TB cohorts.

Conclusions: Several risk factors, including patient age and BMI, were found to be significantly associated with hardware-related complications.

Table of Contents

Glossary of Abbreviations	
Abbreviation	***Meaning***
ORIF	Open reduction internal fixation
P&S	Plate and screw
TB	Tension band
ROH	Removal of hardware
MGH	Massachusetts General Hospital
BWH	Brigham and Women's Hospital

Project Question:

Are any of the following characteristics related to tension band versus plate and screw fixation of non-complicated olecranon fractures:

- Hardware prominence (distance from bone to the outer edge of the plate or tension band construct)
- Patient age
- Patient BMI

Related to hardware removal and/or complication following surgery?

Student Role:

The student was the first author and "primary worker" on this project under the guidance and mentorship of project mentor, Dr. Brandon E. Earp. The student will orchestrate and execute the vast majority of tasks related to this project. This includes: primary data collection via thorough chart review (Epic at BWH and MGH), manual radiographic hardware measurement to assess hardware prominence, efficiently compiling all data, primary literature review (through sources such as PubMed) and ultimately writing and editing the manuscript for submission. Over 300 patient charts were reviewed. The student was in frequent contact with the project mentor throughout all phases.

The statistical analysis was conducted by a PhD statistician who has worked with Dr. Earp extensively. The student also presented this work at two regional and one national conference in both poster and panel presentation format. Through these efforts, the student learned about surgical improvement research, formulating research questions, project organization and adhering to deadlines.

Citation

Bugarinovic G, McFarlane KH, Benavent KA, Janssen SJ, Blazar PE & Earp BE. Risk Factors for Hardware-Related Complications After Olecranon Fracture Fixation. Pending publication in Orthopedics.

Appendix

Abstract

Objectives: The aim of this study is to evaluate risk factors for symptomatic hardware and removal of hardware (ROH) after olecranon open reduction and internal fixation (ORIF) and to assess differences between olecranon locking plate and screws (P&S) or tension band (TB) wire cohorts.

Study Design: Retrospective cohort

Setting: Academic Level I Trauma Center

Patients/Participants: The medical records of 331 patients with olecranon fractures treated with ORIF from 2012-2016 were reviewed. After exclusions, 189 patients were included in the study.

Intervention: ORIF of olecranon fractures using either plate and screw fixation or tension band fixation.

Main Outcome Measures: Complications, ROH and subsequent surgery were assessed and compared between cohorts.

Results: There were 124 cases in the P&S cohort, and 65 in the TB cohort. The overall reoperation rate was 31.2% (59/189). The overall incidence of ROH for all cases was 29.1% (55/189). Patients who required ROH or developed symptomatic hardware were significantly younger than those who did not (P&S $p<0.003$; TB $p<0.004$). Age and BMI were associated with ROH + symptomatic hardware after P&S. Age (but not BMI) was associated with ROH /

symptomatic hardware after TB. Measured hardware prominence was not associated with ROH or ROH + symptomatic hardware for either P&S or TB cohorts.

Conclusion: Several risk factors, including patient age and BMI, were found to be significantly associated with hardware-related complications.

Level of Evidence: III, Therapeutic

Introduction

Fractures of the olecranon account for 10% of all adult upper limb fractures and are most often sustained in a fall from standing height in a middle-aged or elderly patient.[1,2] The majority of olecranon fractures are simple, displaced, non-comminuted fractures,[3] and surgical intervention with open reduction internal fixation (ORIF) is the treatment used for the vast majority of these injuries.[4-7]

There are a variety of techniques and hardware types used in the surgical treatment of olecranon fractures; ORIF with a tension band (TB) construct or with a locking plate and screws (P&S) are the most commonly used. Locking plate fixation has become increasingly popular in recent years with good functional outcomes.[8-10] However, post-operative complications, particularly those requiring hardware removal, are reported in 15%-56% of P&S patients and 20%-92% of TB patients.[11-15]

The aim of our study was to evaluate factors associated with postoperative complications and hardware removal (ROH). Our null hypothesis was that hardware

prominence, patient age, sex, BMI, and type of implant would not be associated with hardware removal.

Methods

We performed an IRB-approved retrospective cohort study of patients with olecranon fractures treated with ORIF at two Level I academic trauma centers from 2012-2016. Three hundred and thirty-one patients were identified through billing records for CPT code 24685 (open treatment of ulnar fracture proximal end, with or without internal or external fixation). Sixty patients were excluded for multiple reasons: surgical treatment other than ORIF with an olecranon plate or tension band (e.g. radial head implants, screws + radial head implants, or screws + K-wires) (38), index surgery being a revision ORIF with primary revision surgery (12), olecranon osteotomy (3) or age younger than 18 (7). This left two hundred and seventy-one patients with ORIF of the olecranon meeting inclusion criteria. Fifty nine patients were then excluded for follow-up less than 180 days and 23 were excluded for lack of postoperative radiographs, leaving 189 (70%) with acceptable follow-up in the indicated cohort. Hence, all patients fulfilling eligibility criteria within the indicated time period were consecutively included.

Patient and surgical demographics, postoperative complications and subsequent surgery information were obtained from review of the electronic medical record and telephone contact.

Hardware prominence was determined by measuring the most immediate post-operative lateral elbow radiograph available in three defined regions along the olecranon (defined in Figures 1 and 2). Within each region, the greatest single distance perpendicular to the most superficial aspect of the cortex to the most prominent corresponding edge of the hardware was recorded. The single greatest value of these three points (X, Y and Z), as well as their cumulative summation, were also recorded. The same individual (GB) performed all measurements using the institutional Picture Archiving and Communication System (PACS) software system.

Statistical Analysis

Hardware prominence (hardware-bone distance), plate type, patient age, and patient BMI were compared with the subsequent development of complication or requirement for ROH. Both overall and stratified incidence of hardware ROH and symptom development was calculated between the variables. All patients fulfilling eligibility criteria within the indicated time period were consecutively included.

Categorical variables were presented using frequencies and percentages, and continuous variables using mean and standard deviation as continuous variables were normally distributed. We assessed if explanatory variables were associated with our primary (i.e. removal of hardware for symptoms) and secondary (i.e. having symptoms or removal of hardware) outcome measures per type of fixation (i.e. plate and screws versus tension band) using the Fisher exact test for categorical variables and the unpaired t-test for continuous variables. Bivariate analyses were complete-case analyses, i.e., excluding cases with missing values

(missing values are indicated in table legends). The impact of age was further explored by dichotomizing age into above and below 60 years of age (median split) and assessing its association with outcome measures per fixation type.

A two-tailed p value (α) below 0.05 was considered significant. A power of (1- β) = 0.80 was employed for all statistical tests. Statistical analyses were performed using Stata 15.0 (StataCorp, USA).

Results

Of the 189 patients meeting inclusion criteria (70M and 119F), 124 fractures (43M and 81F) were treated with P&S and 65 (27M and 38F) with TB. The demographics of the two groups are shown in Table 1. The average length of follow-up was 866 (range: 151-2525) days in the P&S group and 956 (range: 173-2644) days in the TB group.

The overall incidence of ROH for all cases was 55 out of 189 (29.1%), with a rate of 29.0% in the P&S group, and 29.2% in the TB group. An additional 20 patients (10.6%) complained of symptomatic hardware but declined hardware removal (8.9% in the P&S group and 13.9% in the TB group) (Table 2).

The overall combined incidence of ROH and/or symptomatic hardware which was not removed for both P&S and TB was 75 out of 189 (39.7%). For the P&S cohort, the incidence was 37.9% and for the TB cohort, the incidence was 43.1% (Table 3).

Demographic Associations

P&S and TB patients who required ROH or developed symptomatic hardware were significantly younger than those who did not (P&S $p<0.003$; TB $p<0.004$). Patients who underwent P&S olecranon fracture fixation and subsequently required ROH or developed symptomatic hardware were found to have a significantly lower BMI than the patients without ROH or symptomatic hardware ($p<0.045$). In the TB cohort of patients, symptomatic hardware was not associated with BMI ($p=0.347$) (Tables 2 and 3).

In both cohorts, patients over the age of 60 were significantly less likely to undergo hardware removal or develop symptomatic hardware than patients under the age of 60. In the P&S cohort, 27% of patients over the age of 60 underwent ROH or developed symptomatic hardware while 52% of patients under the age of 60 had one of these two outcomes ($p = 0.006$). In the TB cohort, 27% of patients over the age of 60 underwent ROH or developed symptomatic hardware, while 57% of patients under the age of 60 had one of these two outcomes ($p = 0.023$). Furthermore, when symptomatic hardware was excluded, the statistical significance of the association of age with ROH persisted (Table 4). There was no significant difference in ROH amongst the various plate brands utilized in this cohort.

Hardware Associations

Average hardware prominence (and standard deviation), in cm, for all P&S cases was 0.6 (0.2 SD) along region X, 0.6 (0.2 SD) along region Y, 0.7 (0.2 SD) along region Z (regions as defined in Figure 1). The average cumulative prominence was 1.9 (0.4 SD), and the average maximum single point prominence was 0.7 (0.2 SD).

Average hardware prominence (and standard deviation), in cm, for all TB cases was 0.6 (0.3 SD) along region X, 0.4 (0.3 SD) along region Y, 0.3 (0.1 SD) along region Z (regions as defined in Figure 2). The average cumulative and maximum prominences were 1.3 (0.5 SD) and 0.6 (0.3 SD), respectively. This data is shown in Table 2 and Figure 3.

There was no significant difference in hardware prominence in either the P&S or TB groups between patients who required ROH and those who did not (Table 2).

The P&S cohort was found to have significantly higher prominence in regions Y and Z ($p<0.001$), as well as cumulative and maximum prominence compared to the TB cohort ($p<0.001$; $p=0.004$), however, the incidence of ROH or ROH and symptomatic hardware was similar between the two groups (Figure 3).

Other Subsequent Surgery

In the P&S group, 36 patients underwent ROH (29.0%). Of these, 13 patients had at least one additional procedure performed at the time of the ROH, including: revision of hardware (5), incision and drainage (4), ulnar nerve decompression (3), soft tissue procedure (e.g. release, debridement) (2), skin graft (1) and/or capsulectomy (1). An additional 4 patients underwent subsequent surgery without ROH, which included revision of hardware (2), capsulectomy (1), soft tissue release (1) and/or skin graft (1). In the TB group, 19 patients underwent ROH (29.2%). Of these, 7 patients had at least one additional procedure performed at the time of the ROH , including: ulnar nerve release (3), soft tissue release (2), capsulectomy (2), removal of loose body (2), incision and drainage (2), and/or revision of hardware (1) (Table 5).

In total, 59/189 (31.2%) patients who were treated with ORIF of an olecranon fracture underwent subsequent surgery, including 55/189 (29.1%) who required ROH (20 with additional procedures and 4/189 (2.1%) who required additional surgery without ROH.

Discussion

Studies comparing TB and P&S for the treatment of displaced fractures of the olecranon have found similar functional outcomes between the two methods.[13-15] In 2017, Duckworth et al. completed a prospective randomized controlled trial comparing P&S and TB fixation in a cohort of 67 patients with simple isolated, displaced olecranon fractures, finding no significant functional difference at 1-year follow up.[16] Their study did find a higher infection rate following plate fixation, but a higher overall ROH rate following TB technique. A meta-analysis completed by Ren et al. in 2016 found no difference in patient reported outcomes or elbow ROM, however they noted a significant increase in complications among the TB cohort.[9]

Symptomatic hardware is a common complication following olecranon fracture ORIF due to the subcutaneous nature of the olecranon process, with reported rates up to 50-75%.[8] The meta-analysis by Ren et al. found symptomatic hardware to be the most common complication, and Gordon et al. found prominent hardware to be the main perceived complication of plate fixation.[9,17]

Previous studies have examined the relationship between plate prominence and subsequent complications in other injuries.[18-21] Selles et al. found correlation between

hardware prominence of volar plates used for distal radius fracture fixation and subsequent plate removal based on the Soong classification.[22,23] However, no prior studies have analyzed the prominence of the hardware in specific regions along the olecranon and how this relates to ROH and hardware complication.

The relative rates of hardware removal between TB and P&S are controversial. Higher rates of revision surgery and ROH for TB [13-16] and for P&S [24,25] exist in the literature. In addition, other studies have found no significant differences between these two groups.[9,16,26] While we found P&S hardware to be significantly more prominent than TB hardware, there were similar rates of subsequent hardware removal for P&S and TB, 29% for both, indicating plate prominence is not the only factor affecting the decision to proceed with ROH.

While many studies compare outcomes of TB and P&S fixation, few studies have examined other non-hardware factors that affect removal of hardware among these patients. A 2017 retrospective study found reoperation (mostly implant removal) following initial surgery for olecranon fracture to be less common in older patients, mirroring the findings in our study.[27] The association of ROH and age has also been studied for other commonly surgically treated fractures. In 2015, Perdue and colleagues published a study reviewing over 1.6 million patients undergoing ORIF of the tibia or fibula and did not find a significant association between ROH and age.[28] Naumann and colleagues analyzed 997 patient charts following internal fixation of ankle fractures and found implant removal rates due to hardware related complaints decreased with age (hazard ratio 0.79 for each 10-year increase in age, $p<0.001$) while implant removals due to infection increased with age (hazard ratio 1.42 for each 10-year increase in age

p=0.006).[29] A 2012 study by Lovald and colleagues analyzed patients who underwent internal fixation of femoral fractures, and concluded that the mean age of patients undergoing hardware removal was 7 years younger than the mean age of the overall ORIF group ($p<0.0001$).[30] A 2008 study by Sidky and colleagues analyzing 134 tibial fractures requiring intramedullary nail fixation did not find patient age or weight as predictors of implant removal.[31]

Our findings demonstrated that patients over the age of 60 treated with TB or P&S fixation were significantly less likely to require ROH and/or develop symptomatic hardware. This may be due to younger patients having higher demands and/or being more willing to proceed with a second surgery than older patients, who may have more medical comorbidities.

To our knowledge, there is no current literature describing the relationship between BMI and removal of hardware after olecranon fracture fixation. A 1994 retrospective study analyzing 317 charts of patients with elbow fractures found that patients requiring surgical treatment (having displaced fractures) had an increased body mass index compared to those who did not. Overweight body mass and clinical obesity were identified as predisposing factors for elbow and ankle fractures; BMI association with possible subsequent ROH was not explored. In our study, as BMI decreased, the likelihood of ROH and symptomatic hardware increased in P&S patients. This could be due to less subcutaneous tissue overlying their implanted hardware.

There are several limitations to this study. First, removal of hardware may be affected by both surgeon and patient biases and these cannot be accounted for in a retrospective study. For this reason, we also analyzed symptomatic hardware that was not removed. Second,

specific reasons for plate removal may not be entirely explained in the medical record. Third, patients may have undergone hardware removal at outside institutions after our most recent follow-up data available. Fourth, patients may have experienced symptomatic hardware that was not documented. Fifth, radiographic measurement (of hardware prominence) can be affected by variations of the imaging technique. Sixth, a larger sample size might have demonstrated significant differences for other explanatory variables, including hardware prominence.

In conclusion, while ROH and symptomatic hardware are recognized complications associated with olecranon ORIF, P&S and TB fixation demonstrate similar rates of each postoperatively. Although patients treated with P&S demonstrated significantly greater radiographic hardware prominence than the TB group, this was not associated with a difference in symptomatic hardware and ROH rates between the two groups. With both surgical techniques, the chance of a secondary, unplanned surgery remained high at 31.2%. Lower BMI and younger age were both associated with higher rates of symptomatic hardware and ROH and patients should be educated accordingly.

Table 1: Patient and radiographic characteristics of patients undergoing olecranon fracture fixation per surgery type (n=189)

Table 1: Patient and radiographic characteristics of patients undergoing olecranon fracture fixation per surgery type (n=189)			
Patient characteristics	**Plate and screws (n=124)** **Mean (±Standard Deviation)**	**Tension band (n=65)** **Mean (±Standard Deviation)**	***p value***
Age	57 (20)	56 (18)	*0.725*
Body mass index*	26 (5.0)	25 (5.4)	*0.351*
Followup time (in days)	866 (621)	956 (742)	*0.379*
	n (%)	**n (%)**	***p value***
Male	43 (35)	27 (42)	*0.428*
Right side	56 (45)	31 (48)	*0.761*
Open fracture	16 (13)	7 (11)	*0.816*
Complex fracture†	54 (44)	4 (6.2)	***<0.001***
Brand			
Acumed	12 (9.7)	n/a	
Biomet	22 (18)	n/a	
Stryker	3 (2.4)	n/a	*n/a*
Synthes	84 (68)	n/a	
Wright Medical	3 (2.4)	n/a	
Radiographic hardware prominence	**Mean (±Standard Deviation)**	**Mean (±Standard Deviation)**	***p value***
Point X (cm)	0.6 (0.2)	0.6 (0.3)	*0.927*
Point Y (cm)	0.6 (0.2)	0.4 (0.3)	***<0.001***
Point Z (cm)	0.7 (0.2)	0.3 (0.1)	***<0.001***
Cumulative (cm)	1.9 (0.4)	1.3 (0.5)	***<0.001***
Maximum (cm)	0.7 (0.2)	0.6 (.3)	***0.004***

n/a = not applicable.

*Body mass index is available for n=111 (89%) patients who underwent plate and screw fixation, and n=60 (92%) patients who underwent tension band fixation.

†Complex fracture includes any olecranon fracture that is part of a terrible triad or monteggia fracture dislocation or with concomittant distal humerus fracture.

Table 2: Bivariate analysis of patient and radiographic characteristics associated with undergoing removal of hardware for symptoms after olecranon fracture fixation per surgery type (n=189)

Table 2: Bivariate analysis of patient and radiographic characteristics associated with undergoing removal of hardware for symptoms after olecranon fracture fixation per surgery type (n=189)						
	Plate and screws (n=124)			**Tension band (n=65)**		
	No removal of hardware (n=88, 71%)	**Removal of hardware** (n=36, 29%)		**No removal of hardware** (n=46, 71%)	**Removal of hardware** (n=19, 29%)	
Patient characteristics	**Mean (±Standard Deviation)**		***p value***	**Mean (±Standard Deviation)**		***p value***
Age	59 (20)	52 (19)	*0.078*	61 (17)	46 (16)	***0.002***
Body mass index*	27 (5.5)	25 (3.2)	*0.060*	24 (4.5)	27 (6.9)	*0.054*
	n (%)		***p value***	**n (%)**		***p value***
Male	30 (34)	13 (36)	*0.838*	18 (39)	9 (47)	*0.588*
Right side	41 (47)	15 (42)	*0.693*	22 (48)	9 (47)	*0.999*
Open fracture	11 (13)	5 (14)	*0.777*	7 (15)	0 (0)	*0.096*
Complex fracture†	43 (49)	11 (31)	*0.074*	0 (0)	4 (21)	***0.006***
Brand						
Acumed	10 (11)	2 (5.6)		n/a	n/a	
Biomet	15 (17)	7 (19)		n/a	n/a	
Stryker	0 (0)	3 (8.3)	*0.096*	n/a	n/a	*n/a*
Synthes	61 (69)	23 (64)		n/a	n/a	
Wright Medical	2 (2.3)	1 (2.8)		n/a	n/a	
Radiographic hardware prominence	**Mean (±Standard Deviation)**		***p value***	**Mean (±Standard Deviation)**		***p value***
Point X (cm)	0.6 (0.2)	0.6 (0.2)	*0.564*	0.5 (0.2)	0.7 (0.4)	*0.089*
Point Y (cm)	0.6 (0.2)	0.7 (0.2)	*0.056*	0.4 (0.3)	0.5 (0.2)	*0.729*
Point Z (cm)	0.7 (0.2)	0.7 (0.2)	*0.914*	0.3 (0.1)	0.3 (0.1)	*0.661*
Cumulative (cm)	1.8 (0.4)	1.9 (0.4)	*0.273*	1.3 (0.4)	1.5 (0.6)	*0.184*
Maximum (cm)	0.7 (0.2)	0.8 (0.2)	*0.168*	0.6 (0.2)	0.7 (0.4)	*0.156*

*Body mass index is available for n=111 (89%) patients who underwent plate and screw fixation, and n=60 (92%) patients who underwent tension band fixation.

†Complex fracture includes any olecranon fracture that is part of a terrible triad or monteggia fracture dislocation or with concomittant distal humerus fracture.

Table 3: Bivariate analysis of patient and radiographic characteristics associated with symptomatic hardware or undergoing removal of hardware for symptoms after olecranon fracture fixation per surgery type (n=189)

Table 3: Bivariate analysis of patient and radiographic characteristics associated with symptomatic hardware or undergoing removal of hardware for symptoms after olecranon fracture fixation per surgery type (n=189)						
	Plate and screws (n=124)			Tension band (n=65)		
	No symptomatic/removal of hardware (n=77, 62%)	Removal of hardware + symptomatic hardware (n=47, 38%)		No symptomatic/removal of hardware (n=37, 57%)	Removal of hardware + symptomatic hardware (n=28, 43%)	
Patient characteristics	**Mean (±Standard Deviation)**		***p value***	**Mean (±Standard Deviation)**		***p value***
Age	61 (19)	51 (20)	***0.003***	62 (17)	49 (17)	***0.004***
Body mass index*	27 (5.7)	25 (3.4)	***0.045***	25 (4.5)	26 (6.4)	*0.347*
	n (%)		***p value***	**n (%)**		***p value***
Male	25 (32)	18 (38)	*0.562*	17 (46)	10 (36)	*0.454*
Right side	37 (48)	19 (40)	*0.460*	18 (49)	13 (46)	*0.999*
Open fracture	9 (12)	7 (15)	*0.595*	6 (16)	1 (3.6)	*0.130*
Complex fracture†	38 (49)	16 (34)	*0.135*	0 (0)	4 (14)	***0.030***
Brand						
Acumed	9 (12)	3 (6.4)		n/a	n/a	
Biomet	13 (17)	9 (19)		n/a	n/a	
Stryker	0 (0)	3 (6.4)	*0.223*	n/a	n/a	*n/a*
Synthes	53 (69)	31 (66)		n/a	n/a	
Wright Medical	2 (2.6)	1 (2.1)		n/a	n/a	
Radiographic hardware prominence	**Mean (±Standard Deviation)**		***p value***	**Mean (±Standard Deviation)**		***p value***
Point X (cm)	0.6 (0.2)	0.5 (0.2)	*0.688*	0.5 (0.2)	0.6 (0.4)	*0.102*
Point Y (cm)	0.6 (0.2)	0.7 (0.2)	*0.221*	0.4 (0.3)	0.5 (0.2)	*0.599*
Point Z (cm)	0.6 (0.2)	0.7 (0.2)	*0.581*	0.3 (0.1)	0.3 (0.1)	*0.813*
Cumulative (cm)	1.8 (0.4)	1.9 (0.5)	*0.338*	1.3 (0.5)	1.4 (0.5)	*0.214*
Maximum (cm)	0.7 (0.2)	0.8 (0.2)	*0.119*	0.6 (0.3)	0.7 (0.3)	*0.312*

*Body mass index is available for n=111 (89%) patients who underwent plate and screw fixation, and n=60 (92%) patients who underwent tension band fixation.

†Complex fracture includes any olecranon fracture that is part of a terrible triad or monteggia fracture dislocation or with concomittant distal humerus fracture.

Table 4: The association of age with removal of hardware or removal of hardware/presence of symptomatic hardware

Table 4: The association of age with removal of hardware or removal of hardware/presence of symptomatic hardware				
		n (%)	**n (%)**	***p value***
Plate and screws (n=124)		**No removal of hardware**	**Removal of hardware**	
	Age < 60	34 (63)	20 (37)	*0.111*
	Age > 60	54 (77)	16 (23)	
		No symptomatic/removal of hardware	**Removal of hardware + symptomatic hardware**	
	Age < 60	25 (48)	28 (52)	***0.006***
	Age > 60	51 (73)	19 (27)	
Tension band (n=65)		**No removal of hardware**	**Removal of hardware**	
	Age < 60	20 (57)	15 (43)	***0.013***
	Age > 60	26 (87)	4 (13)	
		No symptomatic/removal of hardware	**Removal of hardware + symptomatic hardware**	
	Age < 60	15 (43)	20 (57)	***0.023***
	Age > 60	22 (73)	8 (27)	

*Body mass index is available for n=111 (89%) patients who underwent plate and screw fixation, and n=60 (92%) patients who underwent tension band fixation.

†Complex fracture includes any olecranon fracture that is part of a terrible triad or monteggia fracture dislocation or with concomittant distal humerus fracture.

Table 5: Classification of Revision Surgeries

Type of Surgery	Number, P&S Group	Number, TB Group
Revision Hardware	7	1
Incision & Drainage	4	2
Ulnar Nerve Decompression	3	3
Soft Tissue Release	2	3
Capsulectomy	2	1
Secondary Wound Closure	2	0
Debridement	1	0

Figure 1.

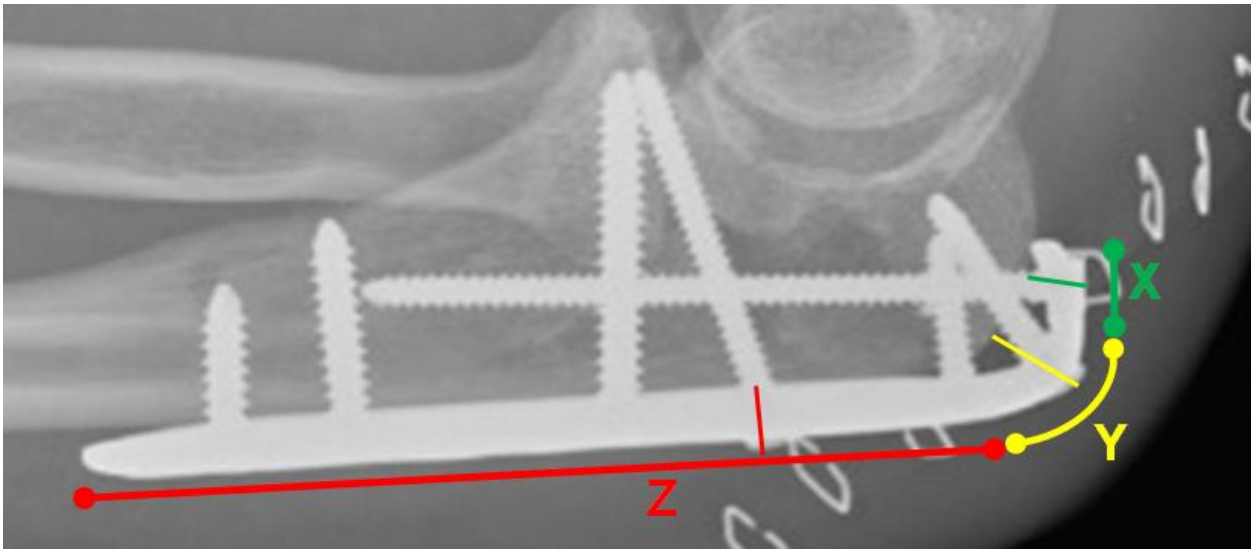

Figure 1. Example of olecranon locking plate measurement. 1) Region X (green) - the most proximal, vertical aspect of the olecranon-hardware interface; 2) Region Y (yellow) - along the curve of the olecranon-hardware interface; and 3) Region Z (red) - the most distal, horizontal aspect of the olecranon-hardware interface.

Figure 2.

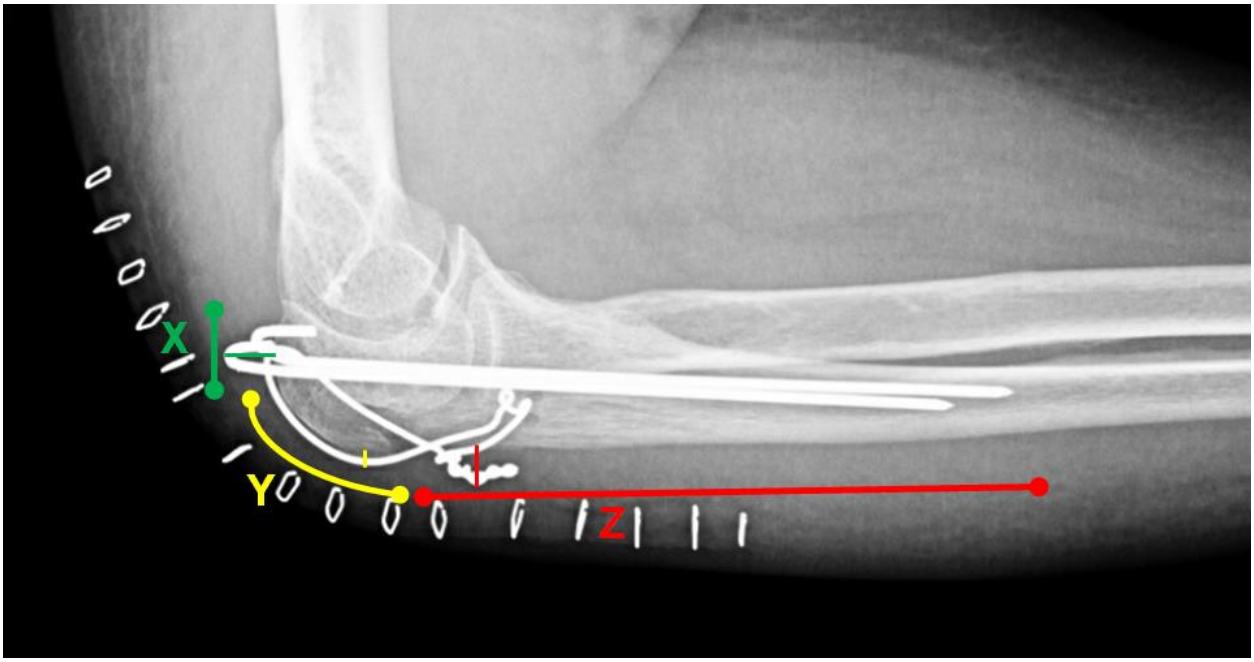

Figure 2: Example of tension band measurement.

Figure 3.

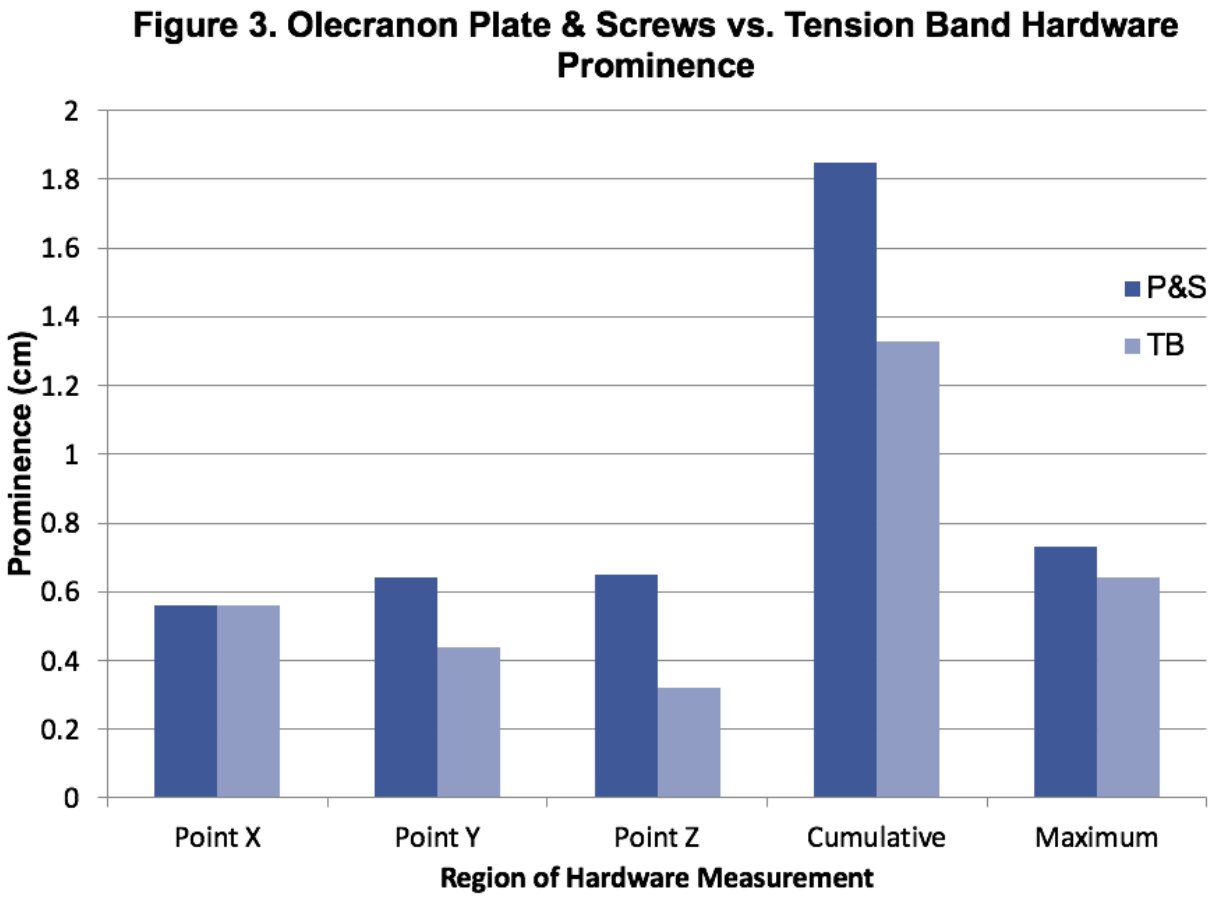

Figure 3. Difference in hardware prominence between P&S and TB.

References

1. Powell AJ, Farhan-Alanie OM, Bryceland JK, Nunn T. The Treatment of olecranon fractures in adults. *Musculoskelet Surg*. 2017;101(1):1-9.
2. Gierer P, Wichelhaus A, Rotter R. Fractures of the olecranon. *Oper Orthop Traumatol*. 2017;29(2):107-114.
3. Duckworth AD, Clement ND, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of fractures of the proximal ulna. *Injury*. 2012 Mar;43(3):343-346.
4. Gallucci GL, Piuzzi NS, Slullitel PAE, Boretto JG, Alfie VA, Donndorff A, De Carli P. Non-surgical functional treatment for displaced olecranon fractures in the elderly. *Bone Joint J.* 2014;96-B:530-534.
5. Parker MJ, Richmond PW, Andrew TA, Bewes PC. A review of displaced olecranon fractures treated conservatively. *J R Coll Surg Edinb.* 1990;35(6):392-4.
6. Duckworth AD, Bugler KE, Clement ND, Court-Brown CM, McQueen MM. Nonoperative management of displaced olecranon fractures in low-demand elderly patients. *J Bone Joint Surg Am*. 2014;96(1):67-72.
7. 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 & Traumatology: Surgery & Research*. 2018;104(1):79-82.
8. Brolin TJ, Throckmorton T. Olecranon Fractures. *Hand Clin*. 2015; 31(4):581-90.
9. Ren YM, Qiao HY, Wei ZJ, Lin W, Fan BY, Liu J, Li A, Kang Y, Liu S, Hao Y, Zhou XH, Feng SQ. Efficacy and safety of tension band wiring versus plate fixation in olecranon fractures: a systematic review and meta-analysis. *J Orthop Surg Res*. 2016; 11(1):137.
10. Bailey CS, MacDermid J, Patterson SD, King GJ. Outcomes of plate fixation of olecranon fractures. *J Orthop Trauma*. 2001;15(8):542-8.
11. De Giacomo AF, Tornetta P 3rd, Sinicrope BJ, Cronin PK, Althausen PL, Bray TJ, Kain MS, Marcantonio A, Sagi C, James CR. Outcomes after plating of olecranon fractures: A multicenter evaluation. *Injury*. 2016;47(7):1466-71.
12. Buijze G, Kloen P. Clinical Evaluation of Locking Compression Plate Fixation for Comminuted Olecranon Fractures. *J Bone Joint Surg Am*. 2009; 91(10):2416–2420.
13. Tarallo L, Mugnai R, Adani R, Capra F, Zambianchi F, Catani F. Simple and comminuted displaced olecranon fractures: a clinical comparison between tension band wiring and plate fixation techniques. *Arch Orthop Trauma Surg*. 2014;134 (8):1107-14.
14. Schliemann B, Raschke MJ, Groene P, Weimann A, Wähnert D, Lenschow S, Kosters C. Comparison of tension band wiring and precontoured locking compression plate fixation in Mayo type IIA olecranon fractures. *Acta Orthop Belg*. 2014;80(1):106-11.
15. Amini MH, Azar FM, Wilson BR, Smith RA, Mauck BM, Throckmorton TW. Comparison of outcomes and costs of tension-band and locking-plate osteosynthesis in transverse olecranon fractures: a matched-cohort study. *Am J Orthop (Belle Mead NJ)*. 2015;44(7):E211-5.
16. Duckworth AD, Clement ND, White TO, Court-Brown CM, McQueen MM. Plate Versus Tension-Band Wire Fixation for Olecranon Fractures: A Prospective Randomized Trial. *J Bone Joint Surg Am*. 2017;99(15):1261-1273.

17. Gordon MJ, Budoff JE, Yeh ML, Luo ZP, Noble PC. Comminuted olecranon fractures: a comparison of plating methods. *J Shoulder Elbow Surg*. 2006;15(1):94-9.
18. Wilson J, Viner JJ, Johal KS, Woodruff MJ. Volar Locking Plate Fixations for Displaced Distal Radius Fractures: An Evaluation of Complications and Radiographic Outcomes. *Hand (N Y).* 2018;13(4):466-472.
19. Singh A, Schultzel M, Fleming JF, Navarro RA. Complications after surgical treatment of distal clavicle fractures. *Orthop Traumatol Surg Res*. 2019. pii: S1877-0568(19)30130-6.
20. Li Y, Helvie P, Farley FA, Abbott MD, Caird MS. Complications After Plate Fixation of Displaced Pediatric Midshaft Clavicle Fractures. *J Pediatr Orthop*. 2018;38(7):350-353.
21. Selvan DR, Machin DG, Perry D, Simpson C, Thorpe P, Brown DJ. The role of fracture reduction and plate position in the aetiology of flexor pollicis longus tendon rupture after volar plate fixation of distal radius fractures. *Hand (N Y).* 2015;10(3):497-502.
22. Selles CA, Reerds STH, Roukema G, van der Vlies KH, Cleffken BI, Schep NWL. Relationship between plate removal and Soong grading following surgery for fractured distal radius. *J Hand Surg Eur*. 2018; 43(2):137–141.
23. Soong M, Earp BE, Bishop G, Leung A, Blazar P. Volar locking plate implant prominence and flexor tendon rupture. *J Bone Joint Surg Am.* 2011;93(4):328-35.
24. Inui A, Kuroda T, Kurosawa T, Kobuku T, Mifune Y, Nishimoto H, Kuroda R. Case Series of Comminuted Olecranon Fracture Treated by Plate Fixation; Do We Have to Remove the Plate? *Kobe J Med Sci.* 2018; 64(3):E115-E118.
25. Matar HE, Miller DJ, Duckett SP. Metalwork Prominence and Operative Interventions for Treating Olecranon Fractures: A Systematic Review of Randomised Controlled Trials. *J Long Term Eff Med Implants*. 2018;28(4):335-345.
26. Matar HE, Ali AA, Buckley S, Garlick NI, Atkinson HD. Surgical Interventions for treating fractures of the olecranon in adults. *Cochrane Database Syst Rev*. 2014;(11):CD010144.
27. Claessen FM, Braun Y, Peters RM, Dyer G, Doornberg JN, Ring D. Factors Associated With Reoperation After Fixation of Displaced Olecranon Fractures. *Clin Orthop Relat Res*. 2016;474(1):193-200.
28. Perdue PW, Rosenbaum YA, Perfetti DC, Kapadia BH, Boylan MR, Jauregui JJ, Paulino CB. What are the Risk Factors for Hardware Removal After Tibia or Fibula Fracture? *J Long Term Eff Med Implants*. 2015;25(4):329-36.
29. Naumann MG, Sigurdsen U, Utvåg SE, Stavem K. Incidence and risk factors for removal of an internal fixation following surgery for ankle fracture: A retrospective cohort study of 997 patients. *Injury*. 2016;47(8):1783-8.
30. Lovald S, Mercer D, Hanson J, Cowgill I, Erdman M, Robinson P, Diamond B. Hardware removal after fracture fixation procedures in the femur. *J Trauma Acute Care Surg*. 2012;72(1):282-7.
31. Sidky A, Buckley RE. Hardware removal after tibial fracture has healed. *Can J Surg*. 2008; 51(4): 263–268.
32. Bostman OM. Body mass index of patients with elbow and ankle fractures requiring surgical treatment. *J Trauma.* 1994;37(1):62-5.