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Original article

Clinical evaluation of double-plate osteosynthesis for olecranon fractures: A retrospective case-control study

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ABSTRACT

Introduction: Single, dorsal plating is a commonly used technique for treating olecranon fractures. Double-plate osteosynthesis is an alternative treatment. Aim of this study was to present the surgical technique using this novel double-plate implant for olecranon fractures and review clinical results, complication rates and revision surgeries. Results were compared to single, dorsal plating.
Hypothesis: Does double-plate osteosynthesis for olecranon fractures improve material's tolerance with respect to osteosynthesis by single dorsal plating?
Patients and methods: Between February 2011 and March 2015, we retrospectively evaluated 47 patients who were included in this study: 25 were treated with a low-profile double-plate osteosynthesis and 22 with an anatomically pre-shaped 3.5 mm locking compression plate (LCP). The 2 groups were the result of a change of implants in our department in 2013. Patient satisfaction, range of motion, patient related outcome scores (Mayo Elbow Performance Score [MEPS], Disabilities of Arm, Shoulder and Hand Score [DASH]), complications and revision surgeries were evaluated. Results between both implant types were statistically compared using the Mann-Whitney U test.
Results: After a mean follow-up of 41 months (range: 25–61), the low-profile double-plate group showed a range of motion of 127°, MEPS of 94 and DASH of 6. The 3.5 mm LCP group was found to have a range of motion of 130°, MEPS of 96 and DASH of 8. No clinical difference was found between groups. A total of 9 revision surgeries after double-plate osteosynthesis were recorded including seven implant removals and two intraarticular screws. One loosening of a screw without revision surgery was reported. The 3.5 mm LCP group had 9 revision surgeries including eight implant removals and one intraarticular screw.
Discussion: Low-profile double-plate osteosynthesis is a safe and effective alternative treatment of olecranon fractures. Subjective and objective clinical outcome measures revealed a low complication rate and excellent results. Still, implant removal due to soft tissue irritation remains an issue. These findings were comparable to common dorsal plate osteosynthesis.
Level of evidence: III, retrospective case-control study.

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1. Introduction

Fractures of the olecranon account for approximately 1% of all upper extremity fractures with an incidence of 12 per 100,000 in the population and 8–11% of all elbow fractures [1]. Surgery remains the gold standard therapy for displaced olecranon fractures. Alternatively, non-operative intervention can be the treatment of choice for elderly patients with multiple co-morbidities and low functional demands [2,3]. The aim of operative treatment is an anatomic reduction with stable fixation for the purpose of early functional mobilisation. A variety of surgical management methods, namely tension band wiring, intramedullary nail fixation or plate osteosynthesis are therefore used. Tension band wiring remains one of most commonly used techniques for simple olecranon fractures [4]. But, in contrast to the common opinion, extensor forces of the triceps muscle are not converted into compressive forces [5,6] and the operative technique is more demanding than believed [7]. Further limitations for choosing tension band wiring as a treatment choice include complex, comminuted and long-distance fractures. Since plate osteosynthesis can bridge such fracture zones and is easy

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to manage, it is becoming a widely utilized standard treatment. Different implants can be used (locking compression plates [8,9], one-third tubular plates [10,11], hook plates [11,12] or reconstruction plates [13,14]) and all continue to be placed at the dorsal ulnar edge. Due to the relatively large size of these implants and poor soft tissue coverage at the dorsal ulna, soft tissue irritation with necessitaty of implant removal can be a consequence.

Rochet et al. first described a technique using two one-third tubular plates with one plate positioned medial and another lateral at each side of the ulna [15]. Ries et al. published a case-series describing double-plate osteosynthesis at the proximal ulna and reported good clinical results with low revision rates [16]. Not only there was improved soft tissue management due to the positioning of the plates, but Hackl et al. reported also less fracture micromotion in double-plate osteosynthesis than in single dorsal plating [17].

The aim of this study was to present the surgical technique using this novel double-plate implant and compare functional results (range of motion, patient related outcome scores), complications rates and revision surgeries to a common single, dorsal locking plate osteosynthesis. Double-plate osteosynthesis for olecranon fractures was expected to improve material's tolerance with respect to osteosynthesis by single dorsal plating.

2. Methods

This retrospective study was performed at a level-I trauma centre after approval from the local ethics committee. All work complied with principles laid down in the Declaration of Helsinki. Between February 2011 and March 2015 electronic patient reports were filtered for the diagnosis of olecranon fracture based on its ICD-10-GM-2016 code (S52.01). Study inclusion criteria were an isolated olecranon fracture, patient age of 18 years or older, and surgery with open reduction and internal fixation by 3.5 mm olecranon locking compression plate (LCP) (Fa. DePuySynthes, Umkirchen, Germany) or Aptus olecranon low-profile double-plate (Fa. Medartis, Basel, Switzerland). The 2 groups were the result of a change of implants used in our department in 2013. A minimum follow-up time of 24 months was required. Patients with previous injuries to the elbow, pre-existing functional limitations, open fractures grade II or higher (according to Östern and Tscherne) [18] or concomitant ligamentous or bony injuries were excluded. All fractures were classified as AO type 21-B1 [19,20]. For further distinction all fractures were additionally classified according to the Schatzker classification by pre-operative radiographs [21]. Patient's reports, surgery protocols and follow-up radiographs were also reviewed.

Seventy-six patients suffering olecranon fracture underwent surgical treatment in our department. Of these patients, 18 did not fit the inclusion criteria of our study while 11 (19%) were lost to follow-up: four had died due to unrelated causes, five could not be contacted and two refused to participate. We finally included 47 patients. After obtaining written informed consent, a one-time follow-up examination was performed recording patient satisfaction (satisfied vs. unsatisfied) and elbow range of motion. Functional results were further evaluated using subjective and objective elbow scores (MEPS: Mayo Elbow Performance Score; DASH: Disabilities of the Arm, Shoulder and Hand Score). Complications were recorded and a history of any revision surgeries was obtained.

Statistical analyses were performed using SPSS for Mac (IBM SPSS Statistics 22, Chicago, Illinois). A *t*-test for independent means was used, when data was normally distributed to the Shapiro-Wilk normality test. If not distributed normally, the results were compared using the Mann-Whitney U test as a two-way analysis of variance for independent factors. Comparing sample sizes smaller than 5 patients, a Fischer's exact test was used for comparison. Comparing relationships between categorical variables the Chi^2 test was used. A p-value < 0.05 was considered statistically significant.

2.1. Surgical technique

Surgery for both implants was performed either in prone or supine positions, depending on surgeon preference. The fracture was approached by a dorsal skin incision. After open reduction, which was held by a clamp or k-wire, the implant was positioned. The 3.5 mm LCP olecranon plate was placed onto the dorsal edge of the ulna (Fig. 1). Due to proximal bowing of the ulna, right and left plate versions were available [22]. A longitudinal incision into the insertion of the triceps-tendon allowed the implant to surround the olecranon tip. After the plate was positioned, it

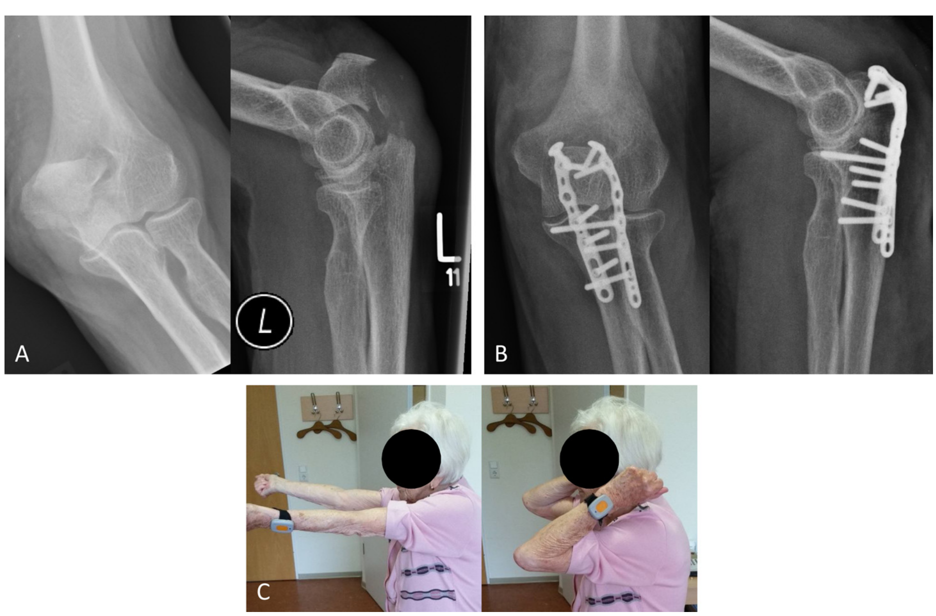

Fig. 1. A 93-year-old female patient with a Schatzker Type B fracture. A. Trauma. B. Open reduction and internal fixation with low-profile double-plate osteosynthesis. C. Clinical findings after 2 years.

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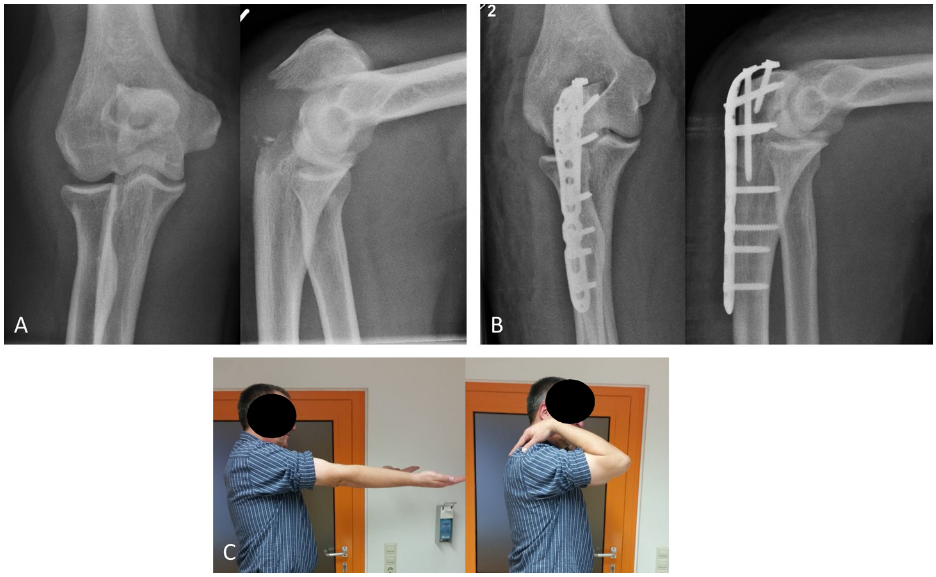

Fig. 2. A 48-year-old male patient with a Schatzker Type B fracture. A. Trauma. B. Open reduction and internal fixation 3.5 mm LCP. C. Clinical findings after 3.5 years.

was temporarily attached onto the shaft of the ulna by a 3.5 mm non-locking screw. Fracture reduction and plate positioning were performed under biplanar fluoroscopy. Remaining screw holes were filled with 3.5 mm locking screws, which were inserted at the end by a torque limiter.

A more extensive preparation for double-plate osteosynthesis was performed after dorsal skin incision (Fig. 2). The musculus (M.) anconeus and M. flexor carpi ulnaris were detached from the ulna. Both soft tissue flaps were used to cover the implant at the conclusion of surgery (Fig. 3). A small medial and lateral incision into the triceps insertion improved the positioning of plates at the olecranon tip. Plates were temporarily attached by a 2.8 mm non-locking screw. After radiological confirmation of anatomic reduction and proper implant positioning, plates were fixed by 2.8 mm locking screws. A torque limiter was not necessary due to existing TriLock technology. Implant position and fracture reduction were controlled again under biplanar fluoroscopic imaging.

All patients were permitted early functional movement without weight bearing for six weeks, starting from the first postoperative day [23].

3. Results

Of the 47 recruited patients, 25 were treated with low-profile double-plate osteosynthesis and 22 with 3.5 mm LCP olecranon plates. The overall mean age was 59 ± 19 years (range: 18–93); 23 patients were women and 24 were men. The mean follow-up was 41 months (range: 25–61). Baseline demographic and fracture characteristics of the two groups were comparable, apart from follow-up time, which was slightly longer for the LCP group (Table 1).

3.1. Low-profile double-plate

In 13 patients, the dominant arm was injured. One patient had an open fracture (grade I according to Oestern and Tscherne) [18]. All patients were operated on within a median of one day (range: 0–6) with an average surgery time of 80 min (range: 29–150). Apart from double-plate osteosynthesis, an additional lag screw was also used in one patient.

One patient reported a loosening of one screw, which perforated the skin about 18 months after surgery. The patient removed the screw himself and no surgical intervention was performed. Seven patients underwent nine revision surgeries. In two cases, postoperative radiographs revealed intraarticular positioning of screws, which were subsequently replaced. The implants of seven patients (28%) were removed after an average of 11 ± 5 months (range: 3–19). The implant was described as disturbing by six patients. One patient suffered an extension deficit and desired implant removal to improve his range of motion. An additional arthrolysis was not performed. All patients reported benefiting from implant removal.

After a mean follow-up time of 35 months, a mean extension/flexion of 127° (range: 80–145°) and pronation/supination of 170° (range: 30–180°) were attained. Compared to the uninjured side, 93% of extension/flexion was possible. An extension deficit of at least 10° compared with the contralateral elbow was found in eight (32%) patients. Pro-/supination was not found to be limited. The mean MEPS was 94 points (range: 65–100) and the DASH-score was 6 points (range: 0–49). The mean pain level reported was 0.6 out of 10 (range: 0–3). One patient (4%) was unsatisfied with the clinical result due to diminished sensation of the ulnar nerve distribution.

Eleven patients provided a follow-up radiograph after an average of 39 ± 25 weeks (range: 6–74). Three patients with a maximum follow-up of 7 weeks showed sign of healing without complete consolidation. All others (follow-up: 13–74 weeks) showed a consolidation of the fracture. No dislocation of any fragment or implant failure was seen.

3.2. 3.5 mm LCP

The dominant arm was affected in eleven cases. One patient had a grade I open fracture (according to Oestern and Tscherne) [18]. All patients were operated on within a median of one day (range: 0–11) with an average surgery time of 86 min (range: 41–141). Apart from plate osteosynthesis in three cases, one additional lag screw – and in one case two additional lag screws – were inserted.

Overall, nine revision surgeries in eight patients were performed. A 45-year-old patient reported persisting intraarticular friction. An additional CT-scan revealed an intraarticular screw, which was substituted with a shorter screw. The remaining eight revision surgeries (36%) were implant removals and were performed on average 15 ± 4 months (range: 8–21) after implantation.

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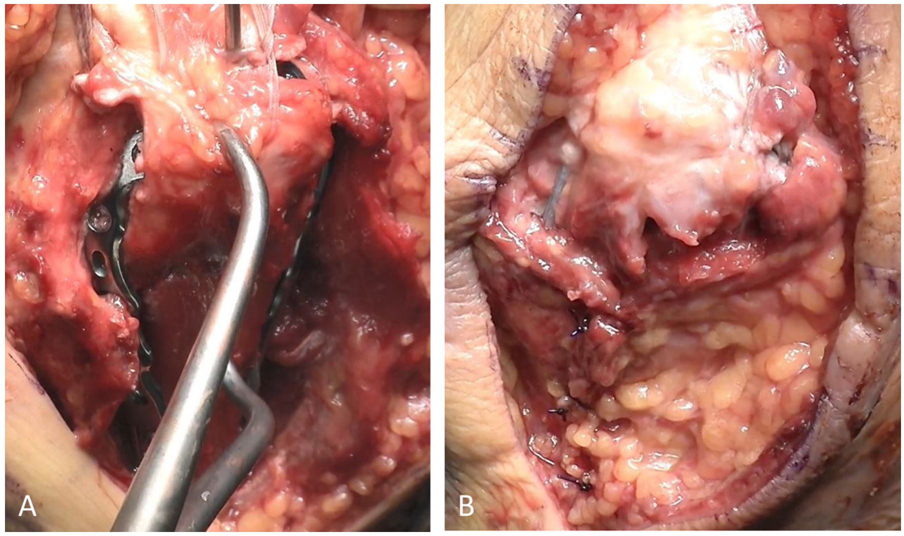

Fig. 3. A. Low-profile double-plate osteosynthesis with additional triceps-tendon augmentation. B. Coverage of the implants with soft tissue at the conclusion of surgery.

Table 1
Baseline patient demographics; 3.5 mm LCP olecranon plate and Aptus olecranon double-plate.

	Total	3.5 mm LCP	Double-plate	*p*-value
Number	47	22	25	
Mean follow-up [months]	41 (25–61)	47 (32–61)	35 (25–48)	0.0001[a]
Age [years]	59 (18–93)	62 (27–90)	56 (18–93)	0.25[a]
Male:female	24:23	9:13	15:10	0.19[b]
Schatzker classification				0.77[c]
Type A	13	7	6	
Type B	23	9	14	
Type C	4	2	2	
Type D	7	4	3	

[a] *t*-test for independent means.
[b] Chi^2 test.
[c] Fischer's exact test.

The implant was described as disturbing by all eight patients. All patients reported improvement after implant removal.

After a mean follow-up of 47 months, mean extension/flexion of 130° (range: 40–150°) and pronation/supination of 174° (range: 95–180°) were attained. Compared to the uninjured opposite side 95% of extension/flexion was possible. Five patients (23%) had an extension deficit of at least 10° compared with the contralateral elbow. Pro-/supination was not found to be limited. The mean MEPS was 96 points (range: 60–100) and DASH-score was 8 points (range: 0–68). The mean pain level according to numeric rating scale (NRS) was 0.2 out of 10 (range: 0–4). Two patients were unsatisfied with their result (9%); one because of a persisting moderate pain level (4 out of 10) and one because of severe limitations of elbow motion (extension/flexion: 0–50–90°).

Ten patients provided a follow-up radiograph after an average of 54 ± 17 weeks (range: 25–82). All showed a consolidation of the fracture without a dislocation of any fragment or implant failure.

3.3. *Low-profile double-plate vs. 3.5 mm LCP*

Comparison of functional results between both implants revealed no differences in range of motion ($p = 0.19$), MEPS ($p = 0.48$) and DASH-score ($p = 0.78$) (Table 2). Surgery durations were comparable (80 vs. 86 min). While one patient from the 3.5 mm LCP group suffered an intraarticular screw, two patients from the low-profile double-plate group did. In addition, one patient suffered loosening of a screw after low-profile double-plate osteosynthesis. Implant were removed due to soft tissue irritation in six patients (24%) after low-profile double-plate osteosynthesis and in eight patients (36%) after 3.5 mm LCP (RR = 0.73, 95% CI 0.29–1.84). At the time of follow-up patient satisfaction was comparable (96% vs. 91%; $p = 0.59$).

4. Discussion

The aim of this study was to describe the technique of double-plate osteosynthesis and compare clinical results, complication rates and revision surgeries of this novel implant with common dorsal plating. Low-profile double-plate osteosynthesis is an effective treatment with good clinical results, low complication rates and high patient satisfaction. Clinical results were comparable to a common single, dorsal locking plate osteosynthesis. Although two plates had to be positioned, surgery duration was not extended. Still there was a high frequency of material removal due to soft tissue irritation and implant costs were higher compared to single dorsal plating.

Nonetheless, this study shows good results of this novel implant in the everyday clinical practice. Although implant removals due to soft tissue irritation showed no significant difference, implant removals were slightly reduced. Therefore this implant should be considered in cases of poor soft tissue covering. Despite the higher costs we see advantages in complex and osteoporotic fractures, since the fracture is packed from two sides, which improves stability [17]. Further discussed disadvantages such as extended operating times were not confirmed.

Table 2
Comparison of 3.5 mm LCP and low-profile double-plate osteosynthesis.

Spalte1	3.5 mm LCP	Low-profile double-plate	*p*-value
Range of motion (extension/flexion)	130° ± 21 (40–150°)	127° ± 15 (80–145°)	0.19[a]
MEPS	96 ± 11 (60–100)	94 ± 10 (65–100)	0.48[a]
DASH	8.3 ± 18 (0–68)	6 ± 11 (0–49)	0.78[a]
Patient satisfaction	20 of 22 (91%)	24 of 25 (96%)	0.59[b]
Time of surgery	86 ± 26 (41–141)	80 ± 29 (29–150)	0.36[b]
Implant removal by soft tissue irritation	8/22 (36%)	6/25 (24%)	0.48[c]

MEPS: Mayo Elbow Performance Score; DASH: Disabilities of the Arm, Shoulder and Hand Score.
[a] Mann-Whitney U test for independent means.
[b] Fischer's exact test.
[c] Chi^2 test.

Tension band wiring remains the most commonly employed technique for the treatment of simple olecranon fractures, in part due to the low cost of implants. Francis et al. analysed the cost effectiveness among tension band wiring and locked plating for Mayo IIA fractures [24]. In 63% of patients, tension band wiring was found to be the most cost-effective solution, saving approximately $1300. This technique, however, had higher revision rates. Comparing the implant costs within this study, the 3.5 mm LCP saved approximately € 236.70 (3.5 mm LCP: € 520.30; double-plate osteosynthesis: € 757.00). Besides the application of a second plate, the higher number of screws resulted in the increased implant costs.

Duckworth et al. first compared tension band wiring and plate osteosynthesis in a prospective randomized trial [25]. Their data revealed no differences between these treatments regarding patient related outcomes (such as range of motion, MEPS and DASH-scores) after a one-year follow-up. However, even here revision surgery was significantly more frequent after tension band wiring (63% vs. 38%; $p = 0.04$).

Due to high revision rates and limitations in treatment of comminuted fractures by tension band wiring, anatomically pre-shaped locking plates have become a more common choice. Alternatively, low-profile double-plate osteosynthesis can be considered. Biomechanically, double-plate osteosynthesis reduces micromotions [17] and the plate position might reduce soft tissue irritation and therefore the rate of revision surgery.

De Giacomo et al. reported a multicentre evaluation of 182 consecutive patients implanted with the Peri-loc™ olecranon plate (Smith Nephew, Memphis, TN) [26]. One hundred and sixty-three patients completed a clinical follow-up period of 24 weeks and attained an average range of motion of 11–133°. An extension deficit of at least 10° (39%) was reported as the most common complication. The DASH-score averaged 10 ± 16. After a follow-up of at least two years, our functional results (i.e. DASH-score and range of motion) were slightly better. According to De Giacomo et al. the majority of clinical benefits were thus attained within the first six months while minor clinical improvements are still possible after more than half a year [26]. An extension deficit remains the most common complication.

Anderson et al. retrospectively evaluated 32 patients treated using the Mayo Congruent Elbow Plate System (Acumed, Hillsborough, California) [27]. Of these patients, 24 were available for outcome scores over a mean follow-up of 2.2 years (range: 0.7–5.1). The mean MEPS was 89 (range: 55–100) and the DASH-score was 24 (range: 0–73). A mean extension/flexion arc of 120 ± 18° could be reached. However, six patients (25%) were found to have an extension deficit of at least 30°. In addition, two non-unions were documented: one due to an infection and another due to non-compliance with weight bearing restriction. Most patients (23 of 24) were either satisfied or mostly satisfied with clinical results.

Siebenlist et al. previously studied the same 3.5 mm anatomically pre-shaped LCP [8], evaluating 13 patients with a mean follow-up of 16 months (range: 8–29). The average arc of flexion was 141° (range: 130–150°) with an extension deficit of 12° (range: 0–35°). The MEPS averaged at 97 (range: 85–100) and the DASH-score at 13 (range: 0–64). Extension strength significantly differed by 14% (45.8 N vs. 53.6 N) when compared to the uninjured side. Strength of flexion, pro- and supination was comparable.

This study found clinical results of low-profile double-plate osteosynthesis to be comparable to those of single, dorsal plate osteosynthesis. Limitations of our study included its retrospective design, a small number of patients, and differences in follow-ups. A change in implant type used in our department (initially 3.5 mm LCP and from 2013 the low-profile double-plate osteosynthesis) should therefore be mentioned. Although patients were followed-up for a minimum of 24 months, this may have been a source of bias. As the 2.7/3.5 mm LCP olecranon plate is the successor of the previous 3.5 mm model, it would be interesting to compare this new implant with the low-profile double-plate in a bigger patient population evaluating rates of soft tissue irritation and implant removal.

5. Conclusion

Low-profile double-plate osteosynthesis is a safe and effective alternative for the treatment of olecranon fractures. Subjective and objective measures revealed excellent clinical outcomes and a low complication rate. Patient satisfaction was high. These findings are comparable to common dorsal plate osteosynthesis. Implant removals due to soft tissue irritation is reduced, but not to a significant level. Therefore, it still remains an issue because of its high number of interventions. Future studies should evaluate larger patient populations and compare this novel implant with modern dorsal implants in regards to soft tissue irritation and implant removal rates.

Disclosure of interest

H. L. and T. S. are consultants for DepuySynthes.

The other authors declare that they have no competing interest.

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Contribution

Dr. Alexander Ellwein: conception and design of the study, analysis and interpretation of data, drafting of the article, final approval of the version to be submitted.

Konstantinos Argiropoulos: acquisition of data, final approval of the version to be submitted.

Rony-Orijit DeyHazra: acquisition of data, revising the article critically for important intellectual content, final approval of the version to be submitted.

Dr. Marc-Frederic Pastor: analysis and interpretation of data, final approval of the version to be submitted.

PD Dr. Tomas Smith: revising the article critically for important intellectual content, final approval of the version to be submitted.

Prof. Dr. Helmut Lill: conception and design of the study, revising the article critically for important intellectual content, final approval of the version to be submitted.

References

[1] Duckworth AD, Clement ND, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of fractures of the proximal ulna. Injury 2012;43:343–6.
[2] 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. Orthop Traumatol Surg Res 2018;104:79–82.
[3] Duckworth AD, Clement ND, McEachan JE, White TO, Court-Brown CM, McQueen MM. Prospective randomised trial of nonoperative versus operative management of olecranon fractures in the elderly. Bone Joint J 2017;99B:964–72.
[4] Chalidis BE, Sachinis NC, Samoladas EP, Dimitriou CG, Pournaras JD. Is tension band wiring technique the "gold standard" for the treatment of olecranon fractures? A long term functional outcome study. J Orthop Surg Res 2008;3:1–6.
[5] 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;44:518–22.
[6] Wilson J, Bajwa A, Kamath V, Rangan A. Biomechanical comparison of interfragmentary compression in transverse fractures of the olecranon. J Bone Joint Surg Br 2011;93B:245–50.
[7] 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. Int Orthop 2014;38:847–55.
[8] Siebenlist S, Torsiglieri T, Kraus T, Burghardt RD, Stöckle U, Lucke M. Comminuted fractures of the proximal ulna – Preliminary results with an anatomically preshaped locking compression plate (LCP) system. Injury 2010;41:1306–11.
[9] Buijze G, Kloen P. Clinical evaluation of locking compression plate fixation for comminuted olecranon fractures. J Bone Joint Surg Am 2009;91:2416–20.
[10] Buijze GA, Blankevoort L, Kloen P. Biomechanical evaluation of fixation of comminuted olecranon fractures: one-third tubular versus locking compression plating. Arch Orthop Trauma Surg 2010;130:459–64.
[11] Schmidt-Horlohé K, Wilde P, Bonk A, Becker L, Hoffmann R. One-third tubular-hook-plate osteosynthesis for olecranon osteotomies in distal humerus type-C fractures: a preliminary report of results and complications. Injury 2012;43:295–300.
[12] Wagner FC, Hölz T, Hohloch L, Suedkamp NP, Reising K. A new hook plate system for olecranon fractures and osteotomies. Clinical results. Obere Extrem 2017;13:38–44.
[13] Wellman DS, Tucker SM, Baxter JR, Pardee NC, Lazaro LE, Smith CS, et al. Comminuted olecranon fractures: biomechanical testing of locked versus minifragment non-locked plate fixation. Arch Orthop Trauma Surg 2017;137:1173–9.
[14] Bailey CS, MacDermid J, Patterson SD, King GJ. Outcome of plate fixation of olecranon fractures. J Orthop Trauma 2001;15:542–8.
[15] Rochet S, Obert L, Lepage D, Lemaire B, Leclerc G, Garbuio P. Proximal ulna comminuted fractures: fixation using a double-plating technique. Orthop Traumatol Surg Res 2010;96:734–40.
[16] Ries C, Wegmann K, Meffert RH, Müller LP, Burkhart KJ. Double-plate osteosynthesis of the proximal ulna. Oper Orthop Traumatol 2015;27:342–56.
[17] Hackl M, Mayer K, Weber M, Staat M, van Riet R, Burkhart KJ, et al. Plate osteosynthesis of proximal ulna fractures – A biomechanical micromotion analysis. J Hand Surg Am 2017;42, 834.e1-834.e7.
[18] Oestern HJ, Tscherne H. Pathophysiology and classification of soft tissue damage in fractures. Orthopade 1983;12:2–8.
[19] Kellam J, Meinberg E, Agel J, Karam M, Roberts C. Introduction: Fracture and Dislocation Classification Compendium – 2018: International Comprehensive Classification of Fractures and Dislocations Committee. J Orthop Trauma 2018;32:S1–10.
[20] Marsh J, Slongo T, Agel J, Broderick J, Creevey W, DeCoster T, et al. Fracture and dislocation classification compendium – 2007: Orthopaedic Trauma Assosciation Classification, Database and Outcomes Committee. J Orthop Trauma 2007;21:S1–163.
[21] Schatzker J. Fractures of the olecranon. In: Schatzker J, Tile M, editors. The rationale of operative fracture care. Berlin: Springer; 2005.
[22] Windisch G, Clement H, Grechenig W, Np T, Pichler W. The anatomy of the proximal ulna. J Shoulder Elbow Surg 2007;16:661–6.
[23] Hackl M, Leschinger T, Uschok S, Müller LP, Wegmann K. Rehabilitation of elbow fractures and dislocations. Obere Extrem 2017;12:201–7.
[24] Francis T, Washington T, Srivastava K, Moutzouros V, Makhni E, Hakeos W. Societal costs in displaced transverse olecranon fractures: using decision analysis tools to find the most cost-effective strategy between tension band wiring and locked plating. J Shoulder Elbow Surg 2017;26:1995–2003.
[25] Duckworth AD, Clement ND, White TO, Court-Brown CM, McQueen MM. Plate versus tension-band wire fixation for olecranon fractures. J Bone Joint Surg Am 2017;99:1261–73.
[26] 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;47:1466–71.
[27] Anderson ML, Larson AN, Merten SM, Scott P. Congruent elbow plate fixation of olecranon fractures. J Orthop Trauma 2007;21:386–93.

Please cite this article in press as: Ellwein A, et al. Clinical evaluation of double-plate osteosynthesis for olecranon fractures: A retrospective case-control study. Orthop Traumatol Surg Res (2019), https://doi.org/10.1016/j.otsr.2019.08.019