



# Long-term follow-up after MIPO Philos plating for proximal humerus fractures

H. Frima<sup>1</sup> · C. Michelitsch<sup>1</sup> · R. B. Beks<sup>2</sup> · R. M. Houwert<sup>2</sup> · Y. P. Acklin<sup>3</sup> · C. Sommer<sup>1</sup>

Received: 10 April 2018 / Published online: 12 November 2018  
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

## Abstract

**Introduction** Minimally invasive plate osteosynthesis (MIPO) has been described as a suitable technique for the treatment of proximal humerus fractures, but long-term functional results have never been reported. The aim of this study was to describe the long-term functional outcome and implant-related irritation after MIPO for proximal humerus fractures.

**Methods** A long-term prospective cohort analysis was performed on all patients treated for a proximal humerus fracture using MIPO with a Philos plate (Synthes, Switzerland) between December 2007 and October 2010. The primary outcome was the QuickDASH score. Secondary outcome measures were the subjective shoulder value (SSV), implant related irritation and implant removal.

**Results** Seventy-nine out of 97 patients (81%) with a mean age of 59 years were available for follow-up. The mean follow-up was 8.3 years (SD 0.8). The mean QuickDASH score was 5.6 (SD 14). The mean SSV was 92 (SD 11). Forty out of 79 patients (50.6%) had implant removal, and of those, 27/40 (67.5%) were due to implant-related irritation. On average, the implant was removed after 1.2 years (SD 0.5). In bivariate analysis, there was an association between the AO classification and the QuickDASH ( $p = 0.008$ ).

**Conclusion** Treatment of proximal humerus fractures using MIPO with Philos through a deltoid split approach showed promising results. A good function can be assumed due to the excellent scores of patient oriented questionnaires. However, about one-third of the patients will have a second operation for implant removal due to implant-related irritation.

**Keywords** Proximal humerus · Fracture · MIPO · Philos · Long-term · Treatment

## Introduction

Proximal humerus fractures are very common and account for 5% of all fractures in the emergency department, with an incidence of 82 per 100,000 people [1–6]. The incidence has a unipolar distribution with a typical patient being relatively fit, female and more than 80 years old [7]. Most patients are treated non-operatively, while one out of five

will undergo surgery even though no clear benefit of operative treatment has been shown [6, 8, 9].

The standard approach for osteosynthesis of proximal humerus fractures is the deltopectoral approach, which generally is considered the open approach [1, 10–12]. Over the past decade, there has been an increasing interest in minimally invasive plate osteosynthesis (MIPO) of proximal humerus fractures through the deltoid split approach [10, 13–19]. Previously reported possible advantages of MIPO are: less soft tissue stripping and a lower risk of injury to the ascending branch of the anterior circumflex humeral artery resulting in lower rates of avascular necrosis (AVN) and shorter operation time [10, 15, 16, 18]. Possible disadvantages are risk of damage to the axillary nerve [10] and, in case of a later shoulder prosthesis, the need for a different second surgical approach. Several studies have reported on the short-term results of this technique [10, 14, 15, 19, 20]. Although long-term results of the open approach for proximal humerus fracture treatment

✉ H. Frima  
herman.frima@ksg.ch

<sup>1</sup> Department of Trauma Surgery, Kantonsspital Graubünden, Loëstrasse 170, 7000 Chur, Switzerland

<sup>2</sup> Utrecht Traumacenter, Universitair Medisch Centrum Utrecht, Heidelberglaan 100, 3584 CX Utrecht, The Netherlands

<sup>3</sup> Department of Orthopaedic Surgery, Kantonsspital Baselland, 4101 Bruderholz, Switzerland

have been reported, little is known about the long-term results after MIPO with Philos [12, 21].

The aim of this study was to analyze the long-term functional outcome after MIPO with Philos for proximal humerus fractures. Additionally, we assessed implant-related irritation and implant removal.

## Methods

### Study design

Between December 2007 and October 2010, 191 patients with a proximal humerus fracture were treated with MIPO through a ‘deltoid split’ approach in our center using the Philos® system (Synthes, Switzerland). Patients were operated by 16 different surgeons. Two of these surgeons performed 50% of all operations. In 2013, Acklin et al. published prospectively gathered data on the short-term outcome of 97 of these patients available for follow-up [10]. In the current study, this cohort was approached and analyzed again to obtain long-term outcome on these patients. Exclusion criteria were death, a second trauma to the operated arm, inability to answer questions, or absence of written consent. This study was approved by the Cantonal Ethic Committee Zürich (KEK-ZH-Nr. 2017-00428).

### Operative procedure and indications

All patients were treated in a MIPO technique. In beach chair position, a minimally invasive anterolateral deltoid split approach was performed. After reduction of the humeral head and non-absorbable suture insertion in the tendons of the rotator cuff, a five hole Philos® plate was inserted. This was done sub-muscular, either percutaneously or with a radiolucent aiming device, under Langenbeck protection to preserve the axillary nerve. The plate was fixed to the humeral head with four locking screws and, depending on bone quality, with two to four conventional or locking screws to the shaft. The non-absorbable sutures were then knotted to the plate for additional stabilization and to prevent secondary dislocation.

Postoperatively, patients were allowed immediate active-assisted mobilization without sling immobilization. Abduction of more than 90° was not allowed in the first six weeks.

Indications for operative treatment were a varus displacement of > 20°, a valgus displacement of > 40°, an increased reclination > 30°, a lateral displacement of > ½ diaphyseal diameter, and/or displacement of the major and/or minor tubercle of > 5–10 mm.

### Baseline characteristics and outcome measures

Baseline characteristics were obtained from the prospectively collected data by Acklin et al. [10]. All patients were contacted by phone by an independent study nurse to assess shoulder function using the QuickDASH questionnaire [22] and the Subjective Shoulder Value (SSV) [23]. Implant removal was assessed using the algorithm of Hulsmans et al. [24]. If patients could not be reached after a minimum of five phone call attempts, their contact person and general practitioner were approached for contact details and the internet was searched for an alternative telephone number. A letter was sent to patients who could not be reached by phone, asking the patient to contact us. Patients were considered lost to follow-up if all these attempts were unsuccessful.

The primary outcome measure was shoulder function as measured by the QuickDASH score [22]. The QuickDASH is a validated measure for disability of the arm, shoulder and hand and provides a summative score on a 100-point scale, where a higher score indicates more disability. A QuickDASH score of less than 15 is considered an excellent result and a score of > 40 indicates poor shoulder function [25].

Secondary outcome measures were SSV and implant-related irritation or implant removal. The SSV is a subjective value for shoulder function determined by the patient after answering the following question: “What is the overall percent value of your shoulder if a completely normal shoulder represents 100%?”, with 100% indicating the best function [23]. The SSV has shown a reliable agreement with the validated Constant Score for measuring shoulder function [26]. Implant removal and implant-related irritation were discussed and analyzed using the algorithm of Hulsmans et al., developed to analyze the presence of implant-related irritation [24]. In addition, all patients were asked if they have had re-operations or were diagnosed with AVN in another hospital.

### Statistical analysis

Data were described using frequencies and percentages for dichotomous and categorical variables, mean and standard deviation (SD) for normally distributed continuous data, and median and interquartile range (IQR) for non-normally distributed continuous data. In bivariate analysis, the association between patients’ characteristics and the QuickDASH and SSV were assessed using a Mann–Whitney test for dichotomous variables (age), a Kruskal–Wallis test for ordinal variables (AO classification [27] and trauma mechanism) and a Spearman’s rank correlation coefficient for

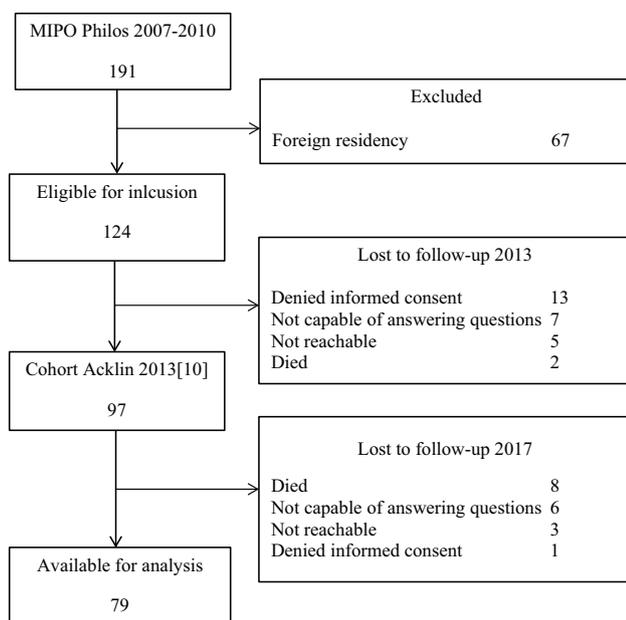
continuous variables (age). A  $p$  value  $< 0.05$  was considered significant which was tested using non-parametrical tests. The analyses were performed with SPSS, version 22.0 (IBM Corp., Armonk, NY) for Windows.

## Results

Informed consent was obtained from all individual participants included in the study. A total of 79 (81%) patients were available for follow-up and included for analysis (Fig. 1). The mean age at the time of accident was 59 (SD  $\pm$  13) years and 37 (47%) patients were male (Table 1). The most common trauma mechanism was injury during skiing or snowboarding (51%). There were 16 (20%) type A, 33 (42%) type B, and 30 (38%) type C fractures according to the AO classification [27]. There were no significant differences in age, trauma mechanism, and AO classification of patients available for follow-up as compared to the initial cohort (data not shown). The mean follow-up duration was 8.3 years (SD 0.8).

The mean QuickDASH score was 5.6 (SD 14) and the mean SSV was 92 (SD 11) (Table 2). A total of 40/79 (50.6%) patients had implant removal on average 1.2 years (SD 0.5) after the initial osteosynthesis (Table 2). Twenty-seven of the 79 (34.2%) patients had implant removal due to implant irritation and 13/79 (16.5%) patients requested implant removal without implant irritation.

In bivariate analysis, there was a significant difference between AO fracture type and QuickDASH score with a



**Fig. 1** Flowchart of patient inclusion

**Table 1** Baseline characteristics

Variable	Baseline cohort ( $n = 79$ ), $n$ (%)
Age (mean, SD)	59 (13)
Male	37 (47)
ASA	
1	28 (35)
2	49 (62)
3	2 (2.5)
4	0 (0)
Dominant hand side	31 (39)
Trauma mechanism	
Ski/snowboard	40 (51)
Low energy	29 (37)
Traffic accident	6 (7.6)
Other	4 (5.1)
AO classification	
A	16 (20)
B	33 (42)
C	29 (38)
Follow-up time in years (mean, SD)	8.3 (0.8)

SD standard deviation

mean of 0.4 (SD 0.9) for type A, 4.6 (SD 9.4) for type B and 9.5 (SD 20) for type C fractures ( $p = 0.008$ ) (Table 3). There was no association of age or trauma mechanism with the QuickDASH score and also no association of age, trauma mechanism or AO classification with the SSV.

Previously published short-term follow-up of this cohort by Acklin et al. showed that all fractures were healed and no hardware failure occurred on follow-up radiographs. The mean radiological follow-up was  $18 \pm 6$  months. There was a small but significant progression of varus displacement visible on last follow-up radiographs compared to postoperative evaluation ( $40^\circ \pm 8$  and  $41^\circ \pm 8$ ;  $p = 0.015$ ), respectively. Secondary screw perforation occurred in seven (7%) patients on average 7 weeks postoperatively and required operative screw(s) replacement. Four patients (4%) had axillary nerve injury with atrophy of the anterior border of the deltoid muscle, however, without clinical consequences.

Furthermore, eight (8%) patients developed some degree of radiological AVN (grade 3–5) in short-term follow-up. With a mean 99 months follow-up, five patients with AVN were available for long-term follow-up. The mean time to diagnosis was 16.7 months, the mean radiological follow-up was 34 months. They had a mean QuickDASH of 21 (SD 29) and a mean SSV of 72 (SD 12) which was significantly worse compared to patients without diagnosis of AVN in short-term follow-up ( $p = 0.001$  and  $p < 0.001$ , respectively). One patient with a QuickDASH of 73 was offered a reversed arthroplasty but she refused. One patient with AVN grade 5 with a QuickDASH

**Table 2** Outcome measures

Variable	Mean (SD)	Median (IQR)
Functional outcome		
QuickDASH	5.6 (14)	0 (0–4.5)
Subjective shoulder value	92 (11)	97 (90–100)
Implant-related irritation/removal ( <i>n</i> , %)		
Implant not removed, no irritation	34 (44)	
Implant not removed, irritation but implant removal not necessary	1 (1.3)	
Implant not removed, irritation, no request for removal due to fear of surgery	2 (2.6)	
Implant not removed, irritation, considering removal	0 (0)	
Implant removed routinely or on patient's request without irritation	13 (17)	
Implant removed due to implant irritation	27 (35)	
Duration till removal of PHILOS plate in years	1.2 (0.5)	

*SD* standard deviation, *IQR* interquartile range

**Table 3** Bivariate analysis

Variable	QuickDASH			SSV		
	Mean (SD)	Median (IQR)	<i>P</i> value	Mean (SD)	Median (IQR)	<i>P</i> value
Age, continuous (coefficient)	0.139		0.223	–0.002		0.988
Age, categorical						
Age < 65	3.8 (13)	0 (0–2.3)	0.06	94 (8.7)	98 (90–100)	0.209
Age > 65	8.4 (16)	2.3 (0–6.8)		89 (13)	95 (80–100)	
Trauma mechanism						
Ski/snowboard	2.0 (3.1)	0 (0–2.3)	0.232	95 (6.6)	99 (90–100)	0.155
Low energy	8.5 (17)	0 (0–6.8)		89 (13)	95 (80–100)	
Traffic accident	20 (33)	5.7 (2.3–14)		83 (16)	90 (75–90)	
Other	1.1 (1.3)	1.1 (0–2.3)		93 (5.4)	93 (89–98)	
AO classification						
A	0.4 (0.9)	0 (0–0)	0.008	93 (7.7)	95 (89–100)	0.844
B	4.6 (9.4)	0 (0–4.5)		93 (10)	98 (90–100)	
C	9.5 (20)	2.3 (0–6.8)		91 (12)	97 (85–100)	

*SD* standard deviation, *IQR* interquartile range

score of 13 and a SSV of 60 is considering a reversed arthroplasty. Of all patients with AVN three had a screw perforation of the head and four had their implant removed. At long-term follow-up there were no new reported cases of AVN based on the interview.

In total, one patient received a reversed arthroplasty. This was because of a symptomatic malunion. The major tubercle was not anatomically reduced and healed with a cranial step. At 80 months follow-up this patient had a QuickDASH of 31 and a SSV of 65. Two other new reported complications occurred. Two patients developed a recurrent shoulder dislocation of whom one was operated for a rotator cuff repair.

## Discussion

MIPO with Philos has been described as a suitable technique for the treatment of proximal humerus fractures, but long-term functional results have never been reported. The aim of this study was to describe the long-term functional outcome and implant-related irritation after MIPO for proximal humerus fractures. In our cohort, we found a very good QuickDASH score and SSV representing an excellent functional outcome at more than 8 years of follow-up after MIPO with Philos for proximal humerus fractures. For this

long-term follow-up, we used patient-reported questionnaires but were not able to obtain an objective clinical and radiological examination. Forty of the 79 patients (50.6%) had implant removal, and of those, 27/40 (67.5%) were due to implant-related irritation. We found a mean Quick-DASH score of 5.6 and a mean SSV of 92, which can be considered an excellent outcome. In 2013, Acklin et al. reported the 1-year follow-up of this cohort and found a constant score of 75 (SD 11) that corresponded to a shoulder function of 91% compared to the uninjured side. Other studies presenting 1 or 2 year follow-ups reported mean DASH scores ranging from 14.5 to 26 after MIPO and 31 to 32 after an open procedure [1, 4, 14, 17, 20]. It is still debated whether further improvement of shoulder function is to be expected 12 months after treatment. Hirschmann et al. found only a slight improvement after 1 year [28]. Other studies published no further improvement at longer follow-up [12, 29].

Few studies have reported on long-term follow-up after operative treatment of proximal humerus fractures but almost all studies investigated the open approach. Ockert et al. investigated 43 patients who were operated on using the open approach with a median follow-up of 10 years and reported a mean DASH score of 24 [12]. Most patients had an excellent outcome, while 16% of the patients were considered to have a poor outcome. Bahrs et al. analyzed 77 patients with a mean follow-up of 8 years; eight patients were operated on using MIPO and 68 via an open approach [21]. They found a good mean DASH score of 12 with 77% of the patients having an excellent/good result and 23% having a satisfactory or worse result. No difference in constant score between surgical approaches nor a correlation with the variables age and AO classification was found.

More than half of the included patients had their implant removed. The majority (68%) because of implant-related irritation and 32% requested implant removal because they did not want the material in their shoulder for the rest of their lives. Our findings are in line with Ockert et al. who reported a 40% implant removal rate [12]. They also found a significant improvement of functional outcome after implant removal. Similarly, another study reported improvement of shoulder function after implant removal among patients with implant-related irritation treated with MIPO Philos plating [30]. In our study, we did not have sufficient data to report on improvement of shoulder function after implant removal. However, based on the study of Acklin et al., the high rate of implant removal in our cohort might have been beneficial for the excellent long-term results [30].

Results of different operative treatments should be put into perspective with regard to the conservative treatment for proximal humerus fractures. In a Cochrane review of eight randomized and quasi-randomized controlled trials, the authors conclude that there was no evidence that supported

the benefit of operative treatment of proximal humerus fractures [8]. But, these results have to be interpreted with caution as the results did not cover two-part tuberosity fractures, fractures in young people, high-energy trauma, fracture–dislocations and head-splitting fractures. Recently, the 5-year follow-up results of the PROFHER trial, the most influential trial leading to conclusions in the Cochrane review, were published in which patients with a proximal humerus fracture were randomized between conservative and operative treatment [29]. In this medium-term follow-up study, the results of 109 patients were reported and no differences in Oxford Shoulder Score and EQ-5D-3L Score were observed. They concluded that there is no evidence that supports the trend of increased surgery for patients with displaced proximal humerus fractures. Nevertheless, there are major shortcomings in this study. First, the study is designed as a superiority study. Only 32% of the screened patients were included (e.g., several patients with clear indication for surgery were excluded). In 11% of cases, fairly inexperienced surgeons (e.g., registrars) performed the operation and 17% were operated on with something other than a plate (e.g., hemi-arthroplasty). So, these results raise serious doubts. In addition, Kruihof et al. presented the long-term follow-up of conservatively treated patients with proximal humerus fractures between 2000 and 2013 [2]. After exclusion, there was data of 410 patients with a good median DASH score of 6.67 at a follow-up of 7.5 years. Sub-analysis revealed a significant better outcome of patients younger than 65 years old at the time of injury. They concluded that long-term functional outcome and quality of life were good in most patients after proximal humeral fractures.

Our study has several limitations that need to be addressed. First, we report on a subgroup of the original cohort that could have led to bias and limited generalizability of the study results. However, compared to the original cohort there were no differences in baseline characteristics in terms of age, trauma mechanism and AO classification. Second, our hospital is situated in a recreational area in the mountains. Therefore, as compared to other hospitals, our patient population consists of younger and many relatively fit patients who were injured during outdoor sports activities. Therefore, our results might not be applicable to the typical proximal humerus fracture patient (female and > 65 years of age) [7]. Nevertheless, in bivariate analysis, there was no association of age or trauma mechanism with functional outcome. Third, the sample size in this study is small and as this was a single center study, no appropriate control group was available. Furthermore, in this long-term follow-up study, we used telephone interviews to get sufficient follow-up. Therefore, we were not able to perform a clinical examination of the shoulder or obtain long-term radiological follow-up. Consequently, no radiological data is available to report

on the actual number of patients that developed AVN or implant failure. It can be argued to what extent radiological grade of AVN translates to limitations experienced by the patient [31], although it seems that patients diagnosed with radiological AVN do have a worse functional outcome in this cohort. In addition, a possible disadvantage of the deltoid split approach is second deltopectoral incision should a prosthesis be necessary in the future. However, this occurred only once in our patient sample. Finally, more than half of the patients were operated by two trauma surgeons dedicated to shoulder surgery while 14 different surgeons operated the other patients, which could have resulted in a performance bias. However, bivariate analysis did not show a difference in functional outcome of patients treated by the two surgeons versus patients treated by the 14 other surgeons. This possibly reflects the effect of in-hospital training and standardized procedure with the introduction of the MIPO technique and postoperative protocol in our hospital.

The results of this study can be of guidance when discussing treatment options for a proximal humerus fracture. The challenge for the future will be to determine which patient will benefit from operative treatment and which patient should be treated conservatively. We recommend operative treatment with MIPO for fit and active patients with a displaced proximal humerus fracture.

## Conclusion

Treatment of proximal humerus fractures using MIPO with Philos through a deltoid split approach showed promising results. A good function can be assumed due to the excellent scores of patient-oriented questionnaires. However, about one-third of the patients will have a second operation for implant removal due to implant-related irritation.

**Acknowledgements** The authors thank Simone Kindle, study nurse, for her efforts in contacting and questioning all patients. They also thank Michelle Reynolds for the excellent copy-editing of this manuscript.

**Funding** There was no external source of funding for this study.

## Compliance with ethical standards

**Conflict of interest** Herman Frima, Christian Michelitsch, Reinier B. Beks, Roderick M. Houwert, Yves P. Acklin and Christoph Sommer declare that they have no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

## References

- Jones CB, Sietsema DL, Williams DK (2011) Locked plating of proximal humeral fractures: is function affected by age, time, and fracture patterns? *Clin Orthop Relat Res* 469(12):3307–3316. <https://doi.org/10.1007/s11999-011-1935-6>
- Kruithof RN, Formijne Jonkers HA, van der Ven DJC, van Olden GDJ, Timmers TK (2017) Functional and quality of life outcome after non-operatively managed proximal humeral fractures. *J Orthop Traumatol*. <https://doi.org/10.1007/s10195-017-0468-5>
- Launonen AP, Lepola V, Saranko A, Flinkkila T, Laitinen M, Mattila VM (2015) Epidemiology of proximal humerus fractures. *Arch Osteoporos* 10:209. <https://doi.org/10.1007/s11657-015-0209-4>
- Olerud P, Ahrengart L, Soderqvist A, Saving J, Tidermark J (2010) Quality of life and functional outcome after a 2-part proximal humeral fracture: a prospective cohort study on 50 patients treated with a locking plate. *J Shoulder Elbow Surg* 19(6):814–822. <https://doi.org/10.1016/j.jse.2009.11.046>
- Palvanen M, Kannus P, Niemi S, Parkkari J (2006) Update in the epidemiology of proximal humeral fractures. *Clin Orthop Relat Res* 442:87–92
- Rangan A, Handoll H, Brealey S, Jefferson L, Keding A, Martin BC, Goodchild L, Chuang LH, Hewitt C, Torgerson D (2015) Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. *JAMA* 313(10):1037–1047. <https://doi.org/10.1001/jama.2015.1629>
- Court-Brown CM, Garg A, McQueen MM (2001) The epidemiology of proximal humeral fractures. *Acta Orthop Scand* 72(4):365–371. <https://doi.org/10.1080/000164701753542023>
- Handoll HH, Brorson S (2015) Interventions for treating proximal humeral fractures in adults. *Cochrane Database Syst Rev* 11:CD000434. <https://doi.org/10.1002/14651858.CD000434.pub4>
- Jawa A, Burnikel D (2016) Treatment of proximal humeral fractures: a critical analysis review. *JBS Rev*. <https://doi.org/10.2106/jbjs.rvw.o.00003>
- Acklin YP, Stoffel K, Sommer C (2013) A prospective analysis of the functional and radiological outcomes of minimally invasive plating in proximal humerus fractures. *Injury* 44(4):456–460. <https://doi.org/10.1016/j.injury.2012.09.010>
- Greiner S, Kaab MJ, Haas NP, Bail HJ (2009) Humeral head necrosis rate at mid-term follow-up after open reduction and angular stable plate fixation for proximal humeral fractures. *Injury* 40(2):186–191. <https://doi.org/10.1016/j.injury.2008.05.030>
- Ockert B, Siebenburger G, Kettler M, Braunstein V, Mutschler W (2014) Long-term functional outcomes (median 10 years) after locked plating for displaced fractures of the proximal humerus. *J Shoulder Elbow Surg* 23(8):1223–1231. <https://doi.org/10.1016/j.jse.2013.11.009>
- Acklin YP, Sommer C (2012) Plate fixation of proximal humerus fractures using the minimally invasive anterolateral delta split approach. *Oper Orthop Traumatol* 24(1):61–73. <https://doi.org/10.1007/s00064-011-0051-9>
- Brunner F, Sommer C, Bahrs C, Heuwinkel R, Hafner C, Rillmann P, Kohut G, Ekelund A, Muller M, Audige L, Babst R (2009) Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. *J Orthop Trauma* 23(3):163–172. <https://doi.org/10.1097/BOT.0b013e3181920e5b>
- Falez F, Papalia M, Greco A, Teti A, Favetti F, Panegrossi G, Casella F, Necozone S (2016) Minimally invasive plate osteosynthesis in proximal humeral fractures: one-year results of a prospective multicenter study. *Int Orthop* 40(3):579–585. <https://doi.org/10.1007/s00264-015-3069-z>

16. Lin T, Xiao B, Ma X, Fu D, Yang S (2014) Minimally invasive plate osteosynthesis with a locking compression plate is superior to open reduction and internal fixation in the management of the proximal humerus fractures. *BMC Musculoskelet Disord* 15:206. <https://doi.org/10.1186/1471-2474-15-206>
17. Oh HK, Cho DY, Choo SK, Park JW, Park KC, Lee JI (2015) Lessons learned from treating patients with unstable multifragmentary fractures of the proximal humerus by minimal invasive plate osteosynthesis. *Arch Orthop Trauma Surg* 135(2):235–242. <https://doi.org/10.1007/s00402-014-2138-x>
18. Sohn HS, Jeon YS, Lee J, Shin SJ (2017) Clinical comparison between open plating and minimally invasive plate osteosynthesis for displaced proximal humeral fractures: a prospective randomized controlled trial. *Injury* 48(6):1175–1182. <https://doi.org/10.1016/j.injury.2017.03.027>
19. Sohn HS, Shin SJ (2014) Minimally invasive plate osteosynthesis for proximal humeral fractures: clinical and radiologic outcomes according to fracture type. *J Shoulder Elbow Surg* 23(9):1334–1340. <https://doi.org/10.1016/j.jse.2013.12.018>
20. Laflamme GY, Rouleau DM, Berry GK, Beaumont PH, Reindl R, Harvey EJ (2008) Percutaneous humeral plating of fractures of the proximal humerus: results of a prospective multicenter clinical trial. *J Orthop Trauma* 22(3):153–158. <https://doi.org/10.1097/BOT.0b013e3181694f7d>
21. Bahrs C, Kuhle L, Blumenstock G, Stockle U, Rolauffs B, Freude T (2015) Which parameters affect medium- to long-term results after angular stable plate fixation for proximal humeral fractures? *J Shoulder Elbow Surg* 24(5):727–732. <https://doi.org/10.1016/j.jse.2014.08.009>
22. Beaton DE, Wright JG, Katz JN (2005) Development of the QuickDASH: comparison of three item-reduction approaches. *J Bone Joint Surg Am* 87(5):1038–1046. <https://doi.org/10.2106/jbjs.d.02060>
23. Jost B, Pfirrmann CW, Gerber C, Switzerland Z (2000) Clinical outcome after structural failure of rotator cuff repairs. *J Bone Joint Surg Am* 82(3):304–314
24. Hulsmans MH, van Heijl M, Houwert RM, Hammacher ER, Meylaerts SA, Verhofstad MH, Dijkgraaf MG, Verleisdonk EJ (2017) High irritation and removal rates after plate or nail fixation in patients with displaced midshaft clavicle fractures. *Clin Orthop Relat Res* 475(2):532–539. <https://doi.org/10.1007/s11999-016-5113-8>
25. Angst F, Schwyzer HK, Aeschlimann A, Simmen BR, Goldhahn J (2011) Measures of adult shoulder function: Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and its short version (QuickDASH), Shoulder Pain and Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form, Constant (Murley) Score (CS), Simple Shoulder Test (SST), Oxford Shoulder Score (OSS), Shoulder Disability Questionnaire (SDQ), and Western Ontario Shoulder Instability Index (WOSI). *Arthritis Care Res* 63(Suppl 11):S174–S188. <https://doi.org/10.1002/acr.20630>
26. Gilbert MK, Gerber C (2007) Comparison of the subjective shoulder value and the constant score. *J Shoulder Elbow Surg* 16(6):717–721. <https://doi.org/10.1016/j.jse.2007.02.123>
27. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, Prokuski L, Sirkin MS, Ziran B, Henley B, Audige L (2007) Fracture and dislocation classification compendium—2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma* 21(10 Suppl):S1–S133
28. Hirschmann MT, Fallegger B, Amsler F, Regazzoni P, Gross T (2011) Clinical longer-term results after internal fixation of proximal humerus fractures with a locking compression plate (PHILOS). *J Orthop Trauma* 25(5):286–293. <https://doi.org/10.1097/BOT.0b013e3181f2b20e>
29. Handoll HH, Keding A, Corbacho B, Brealey SD, Hewitt C, Rangan A (2017) Five-year follow-up results of the PROFHER trial comparing operative and non-operative treatment of adults with a displaced fracture of the proximal humerus. *Bone Joint J* 99-b(3):383–392. <https://doi.org/10.1302/0301-620x.99b3.bjj-2016-1028>
30. Acklin YP, Michelitsch C, Sommer C (2016) Elective implant removal in symptomatic patients after internal fixation of proximal humerus fractures improves clinical outcome. *BMC Musculoskelet Disord* 17:119. <https://doi.org/10.1186/s12891-016-0977-z>
31. Robinson CM, Khan LA, Akhtar MA (2006) Treatment of anterior fracture-dislocations of the proximal humerus by open reduction and internal fixation. *J Bone Joint Surg Br* Vol 88(4):502–508. <https://doi.org/10.1302/0301-620x.88b4.17195>