Arch Orthop Trauma Surg (2017) 137:651–662
DOI 10.1007/s00402-017-2645-7

TRAUMA SURGERY

Comparative analysis of locking plate versus hook plate osteosynthesis of Neer type IIB lateral clavicle fractures

Benjamin Erdle[1] · Kaywan Izadpanah[1] · Martin Jaeger[1] · Patrizia Jensen[1] · Lukas Konstantinidis[1] · Jörn Zwingmann[1] · Norbert P. Südkamp[1] · Dirk Maier[1]

Received: 9 September 2016 / Published online: 20 March 2017

Abstract
Introduction Controversy exists on optimal operative treatment of vertically unstable Neer IIB lateral clavicle fractures. Aim of this study was to analyse and compare clinical and radiological results and complications of locking plate osteosynthesis (LPO) versus hook plate osteosynthesis (HPO) with acromioclavicular joint (ACJ) stabilization. The hypothesis was, that HPO would recreate coracoclavicular stability more effectively and potentially lead to a superior outcome.
Methods This retrospective, observational cohort study included 32 patients (19 HPO, 13 LPO) with a mean age of 44.1 ± 14.2 years at surgery. The mean follow-up period was 54.2 months (range 25.2–111.4 months). Besides standard radiography, bilateral coracoclavicular distances were assessed by means of preoperative and follow-up stress radiographs after implant removal. Clinical outcome measures included the Constant score (CS), the Oxford shoulder score (OSS), the subjective shoulder value (SSV) and the Taft score (TS).
Results Bone union occurred in all but one patient and proved to occur delayed in five patients (15.6%). Radiographical healing required a mean of 4.2 ± 4.0 months irrespective of the type of osteosynthesis. At follow-up, mean coracoclavicular distance was increased by 34% (±36) without significant differences between both groups. HPO patients obtained a significantly lower TS (HPO: 9.5 ± 1.5 points, LPO: 11.1 ± 1.3 points; $p = 0.005$). Other mean score values did not differ (CS: 90.1 ± 7.4 points, OSS: 43.2 ± 9.2 points, SSV: 91.1 ± 14.7%). Sixteen patients (50.0%) experienced complications. Overall prevalence of complications was significantly higher in the HPO group ($p = 0.014$).
Conclusions Both HPO and LPO were equally effective in relation to restoration of vertical stability, overall functional outcome and fracture consolidation in treatment of Neer IIB fractures. Contrary to our hypothesis, HPO was not associated with superior recreation of the coracoclavicular distance. Considerable drawbacks of HPO were an inferior ACJ-specific outcome (Taft-Score) and a higher overall complication rate.
Level of evidence IV.

Keywords Distal clavicle fracture · Neer type IIB · Coracoclavicular distance · Locking plate · Clavicular hook plate · Acromioclavicular joint

✉ Benjamin Erdle
benjamin.erdle@uniklinik-freiburg.de

Kaywan Izadpanah
kaywan.izadpanah@uniklinik-freiburg.de

Martin Jaeger
martin.jaeger@uniklinik-freiburg.de

Patrizia Jensen
patrizia.jensen@gmx.com

Lukas Konstantinidis
lukas.konstantinidis@uniklinik-freiburg.de

Jörn Zwingmann
joern.zwingmann@uniklinik-freiburg.de

Norbert P. Südkamp
norbert.suedkamp@uniklinik-freiburg.de

Dirk Maier
dirk.maier@uniklinik-freiburg.de

[1] Department of Orthopaedics and Trauma Surgery, Medical Centre/Faculty of Medicine - Albert-Ludwigs-University of Freiburg, Hugstetter Strasse 55, 79106 Freiburg, Germany

Introduction

Controversy exists on optimal treatment of vertically unstable Neer type II lateral clavicle fractures. Surgical stabilization is usually recommended, since non-operative treatment is associated with high rates of non-union [23]. On the other hand, operative treatment may be complicated by delayed union or non-union, secondary dislocation, implant failure, persistent coracoclavicular instability and peri-implant fracture.

Craig modified Neer's classification and divided unstable type II lateral clavicle fractures into type IIA and type IIB fractures [6]. Neer IIA fractures are located medial to both coracoclavicular ligaments, whereas Neer IIB fractures run in between the trapezoid and conoid ligament. In Neer IIB fractures, the intact trapezoid ligament remains attached to the lateral fragment. Rupture of the conoid ligament effects pronounced vertical instability, which may persist even after bone union. Therefore, effective treatment of Neer IIB fractures should aim for both bone union and recreation of coracoclavicular stability. Valid interpretation of the efficacy of various treatment modalities necessitates clear differentiation between both fracture types. However, very few outcome studies strictly distinguished between type IIA and IIB fractures [2, 19, 25–27]. Thereof, only one study performed preoperative and follow-up stress radiographs for dynamic evaluation of coracoclavicular stability [25].

Despite rates of delayed union or non-union of up to 10%, literature reports satisfactory clinical outcomes following isolated locking plate osteosynthesis (LPO) without additional coracoclavicular stabilization [2, 8, 18, 27, 31]. For treatment of Neer IIB fractures, Shin et al. [27] showed that LPO alone may not fully recreate preinjury coracoclavicular distance. In this context, hook plate osteosynthesis (HPO) as an ACJ-spanning procedure could recreate coracoclavicular stability more effectively and hereby potentially lead to a superior functional outcome compared to isolated LPO. On the contrary, a systematic review suggested a higher prevalence of complications following HPO [23]. HPO may cause complications such as ACJ arthrosis, acromial osteolysis or subacromial impingement syndrome and requires secondary surgery for implant removal.

To our best knowledge, no previous study compared efficacy of LPO versus HPO by means of preoperative and follow-up bilateral stress radiographs. Aim of this retrospective, comparative cohort study was to analyse and compare radiological results, functional outcomes and complications of LPO versus HPO. Our hypothesis was, that HPO would recreate coracoclavicular stability more effectively. As a result, radiological and clinical outcomes of HPO could also prove to be superior.

Materials and methods

The study was approved by the local Ethics Committee. Informed consent was obtained from all patients prior to study inclusion. We employed a retrospective, comparative cohort study design defining the following inclusion criteria: (1) acute, isolated Neer IIB lateral clavicle fracture with vertical instability as proven by means of preoperative, bilateral anterior–posterior stress radiographs, (2) operative treatment using LPO or HPO, (3) minimal follow-up period of 24 months after surgery and (4) history of painless and unrestricted shoulder function prior to trauma. Exclusion criteria were: (1) concomitant injuries of the affected shoulder girdle or concomitant injuries impairing function of the affected shoulder girdle, and (2) incomplete preoperative diagnostics.

A retrospective database research of the last 12 years identified 130 patients who had undergone operative treatment for acute lateral clavicle fractures at our institution. Thereof, 23 patients showed other than Neer II fractures or had been treated with other methods of fixation. A total of 107 cases had Neer II (A + B) lateral clavicle fractures and were treated either with LPO or HPO. Thereof, 45 patients had not received preoperative bilateral anterior–posterior stress radiographs or suffered from previous or concomitant injuries/pathologies. Vertical instability, defined as caudal displacement of the lateral fragment exceeding one width of the clavicular shaft in AP stress radiographs, was found in 37/62 cases. Thus, 37 patients met all inclusion criteria and were eligible for study inclusion. However, three individuals could not be contacted and another two refused study participation. The study comprised 32 patients (4 female, 28 male) corresponding to an inclusion rate of 86.5%.

The right shoulder (dominant in $n = 14$) was affected in 15 cases. Injury mechanisms consisted of 18 bicycle and 3 motorcycle accidents, 1 car accident, 4 skiing accidents, 1 soccer injury and 5 falls while walking. Standardized preoperative radiological examination included an anterior–posterior view, an anterior–posterior with 30° cephalic tilt (Fig. 1) and bilateral anterior–posterior stress radiographs with 10 kg vertical loading (Fig. 2). Two experienced orthopaedic surgeons independently reviewed all radiographs and consistently agreed on the diagnosis of type IIB fractures according to Craig's modification of the Neer classification [6]. Caudal lengths of the lateral fragments were measured in the anterior–posterior views. Count of fragments served for assessment of fracture severity and comminution.

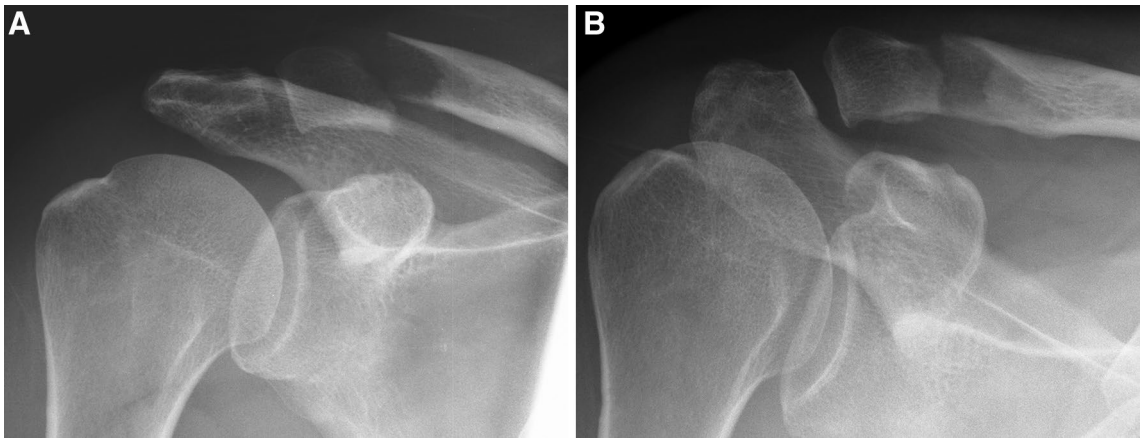

Fig. 1 Preoperative radiographs of a Neer IIB fracture without weight show moderate displacement in the anterior–posterior view (**a**) and the anterior–posterior with 30° cephalic tilt (**b**)

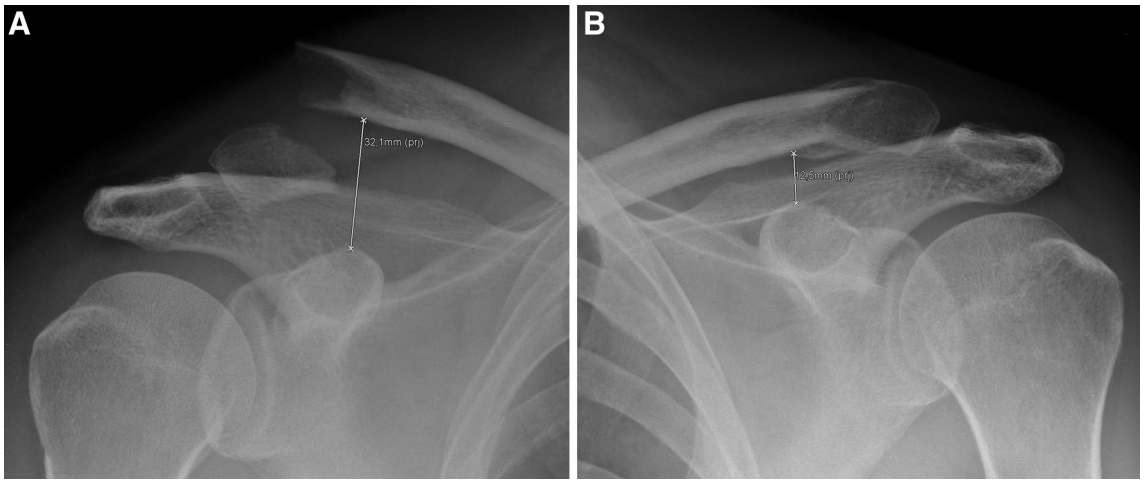

Fig. 2 Preoperative bilateral anterior–posterior stress radiography with 10 kg vertical loading shows distinct coracoclavicular instability of the affected side (**a**) compared to the healthy side (**b**). The coracoclavicular distance is increased by 157%

Cohort profiles

Table 1 displays overall and cohort-specific patient and fracture profiles. HPO and LPO cohort profiles were statistically comparable with regard to age, gender, follow-up period, fracture profiles and extent of coracoclavicular instability ($p > 0.05$).

Operative treatment and postoperative rehabilitation

All surgeries were performed in general anaesthesia and supine position with 30° of chest elevation. A 4–5 cm sabre cut incision was performed medial to the ACJ. The deltoid-trapezoidal fascia was incised in line with the lateral clavicle. After exposure and reduction of the fracture, K-wires were inserted for temporary fixation. For LPO ($n = 13$), either a 3.5 mm LCP T-plate ($n = 7$) (DepuySynthes) designed for distal radius fractures or an anatomically precontoured 2.7/3.5 mm LCP superior lateral clavicle plate ($n = 6$) (DepuySynthes) was used for definite fixation. All 19 HPO patients received a 3.5 mm LCP clavicular hook plate (DepuySynthes, West Chester, USA). Choice of implant exclusively depended on the surgeon's personal preference and was not related to morphology or severity of the fracture or subjective assessment of bone quality. Quality of reduction and position of implants were controlled with intraoperative fluoroscopy using standardized AP projections (Fig. 3). In all cases, the ACJ was found to be stable and the lateral fragment(s) could serve as a reference for reduction in the vertical and horizontal plane. Intraoperatively, the lateral fragment(s) precisely lined up with the medial shaft fragment, aiming for the best possible CCD recreation with either method of fixation. We did not perform

Table 1 Overall and cohort-specific profiles

	Total	HPO	LPO	*p*
Patients	32	19	13	
Age (years)	44.1 (±14.2)	44.3 (±14.9)	43.7 (±13.7)	0.85
Follow-up (months)	54.2 (±20.1)	54.9 (±19.8)	53.3 (±19.6)	0.85
Length lateral fragment (mm)	21.3 (±7.9)	19.5 (±5.6)	23.9 (±10.1)	0.38
Fragment count	2.59 (±0.56)	2.63 (±0.50)	2.54 (±0.66)	0.81
CCD% preop	+172 (±83)	+166 (±74)	+180 (±98)	0.92

HPO hook plate osteosynthesis, *LPO* locking plate osteosynthesis, *Age* mean age at surgery (years), *CCD% preop*. percentage deviation of coracoclavicular distance of injured compared to healthy, contralateral side as measured in preoperative, bilateral AP stress radiographs

any coracoclavicular stabilization procedure or ligament repair. Finally, the deltoid-trapezoidal fascia and the wound were closed with absorbable suture material.

For a postoperative period of 1–3 days, temporary sling application served for pain relief and comfort. Pain-adapted active range of motion was allowed from day one after surgery. HPO patients were instructed to respect an abduction limit of 90° until radiographical proof of healing to avoid implant-related complications. In LPO patients, full range of motion was usually achieved within 3–6 postoperative weeks. However, patients were instructed to strictly avoid mechanical stress and heavy labour until radiographical proof of fracture consolidation. Standardized radiographs (anterior–posterior, anterior–posterior with 30° cephalic tilt, transaxillary view) were routinely performed postoperatively, after 6 weeks, 3, 4.5, 6, 12 months and then annually as needed. LPO implants were only removed in case of local irritation and/or on explicit patient's request. Removal of hook plates was recommended after radiographical proof of fracture consolidation.

Analysis of outcome and complications

Follow-up examinations were conducted from 3/2013 to 6/2015 and included standardized clinical and radiological evaluation of all included patients. Mean follow-up period was 54.2 months (range 25.2–111.4 months). An independent investigator performed comprehensive clinical examinations of the shoulder and the ACJ including assessment of active and passive range of motions. The absolute Constant score (CS) [5], Oxford shoulder score (OSS) [7], subjective shoulder value (SSV) [9] and Taft score (TS) [29] were used as functional outcome measures. According to Boehm [4], Constant score results were classified as excellent (100–91 points), good (90–81 points), satisfactory (80–71 points), fair (70–61 points) or poor (<60 points). Radiological follow-up examinations after implant removal consisted of an anterior–posterior view with 30° cephalic tilt and bilateral anterior–posterior stress radiographs with 10 kg vertical loading (Fig. 4). Preoperatively and at follow-up, CCDs were bilaterally measured as distances between the most superior border of the coracoid and the undersurface of

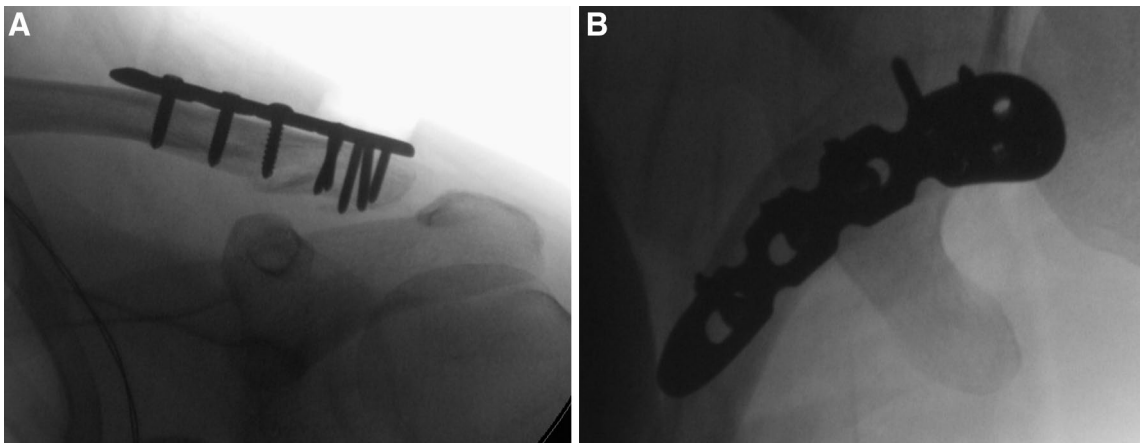

Fig. 3 Osteosynthesis of a Neer IIB fracture with an anatomically precontoured 2.7/3.5 mm LCP superior lateral clavicle plate (DepuySynthes). Correct reduction and implant position are controlled by intraoperative fluoroscopy. Anterior–posterior view (**a**) and transaxillary view (**b**)

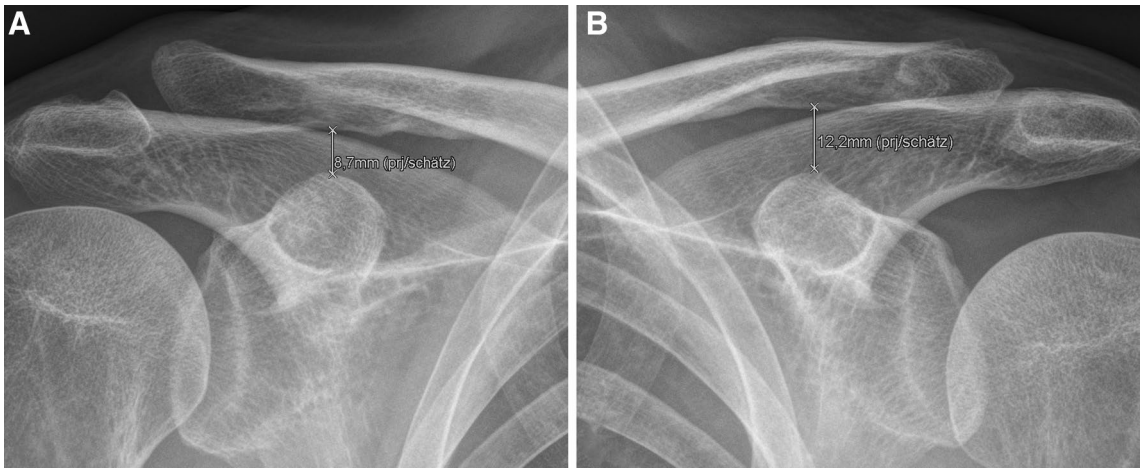

Fig. 4 Dynamic assessment of coracoclavicular stability of a consolidated Neer IIB fracture following 3.5 mm LCP clavicular hook plate osteosynthesis (DepuySynthes) and implant removal. Follow-up bilateral anterior–posterior stress radiography with 10 kg vertical loading shows partial persistent coracoclavicular instability of the affected side (**a**) compared to the healthy side (**b**). The coracoclavicular distance is increased by 40%

the clavicle at the lateral border of the conoid tubercle (Figs. 2, 4). Since all AP stress views were conducted bilaterally, vertical stability of the injured side could be compared to the healthy, contralateral side on the basis of virtually identical projections. CCD differences were expressed as percentage deviations of the affected related to healthy, contralateral side. All radiographs were evaluated for time periods required for fracture consolidation and adverse events including typical reported complications of both procedures such as secondary dislocation, implant failure and loosening, peri-implant fracture, acromion osteolysis, postoperative ACJ arthrosis, nonunion or delayed union. Delayed union was defined as incomplete radiographical consolidation >6 months after surgery.

Statistics

Statistical analysis was performed using the software SPSS version 22 (SPSS Inc., Chicago, IL, USA). Descriptive results are given as mean values with ranges or standard deviations (±). With independent samples, a Mann–Whitney *U* test was used for non-parametric group comparisons. A Chi-square test was used for distributional analysis. We defined 95% confidence intervals. Statistical significance was assumed for p values <0.05. Sample size calculation revealed a minimum cohort size of $n=11$ ($p=0.8$, $\alpha=0.05$) to detect a clinically relevant CCD difference of more than 25% (corresponding to a Rockwood-3 scenario) compared to the healthy side allowing for a modest loss to follow-up.

Results

Clinical outcome

Table 2 summarizes overall and cohort-specific (HPO versus LPO) clinical and radiological outcome measures for direct comparison. Patients treated with HPO obtained a significantly ($p=0.005$) inferior TS compared to patients treated with LPO (HPO: 9.5 ± 1.5 points, LPO: 11.1 ± 1.3 points). Inferior radiological subscores of the HPO cohort resulted from a higher prevalence of posttraumatic ACJ arthrosis. All other scores did not show significant differences between the LPO and HPO cohort. Mean follow-up CS was 90.3 points (range 67–100). Seventeen patients (53.1%) achieved excellent and 13 patients (40.6%) good results. One patient (3.1%) aged 73 years at follow-up obtained a satisfactory outcome. This patient showed a symptomatic subacromial impingement syndrome with a mildly positive starter test. Radiographical follow-up showed complete bone union, symmetrical CCD restoration and a normal acromiohumeral distance. However, a rounded 8×4 mm heterotopic ossification along the course of the conoid ligament was apparent. Another patient (3.1%) with a fair result suffered from symptomatic nonunion of the lateral clavicle following hook plate osteosynthesis. All but the two latter patients (93.8%) graded their shoulder functions as excellent or good and could return to previous activities of profession, daily living and sports. All hook plates were removed after a mean time-period of 4.7 months. All but three LPO implants (76.9%) were removed after a mean time-period of 12.5 months on explicit patient's request due to a subjective sense of local irritation.

Table 2 Overall and cohort-specific clinical and radiological outcome

	Total	HPO	LPO	*p*
Patients	32	19	13	
CS	90.1 (±7.4)	88.7 (±8.8)	92.2 (±4.2)	0.45
OSS	43.2 (±9.2)	40.8 (±11.5)	46.5 (±2.5)	0.42
SSV	91.1 (±14.7)	88.7 (±18.4)	94.4 (±6.5)	0.23
TS_{tot}	10.1 (±1.6)	9.5 (±1.5)	11.1 (±1.3)	0.005*
TS_{subj}	3.4 (±0.9)	3.3 (±1.1)	3.5 (±0.7)	0.85
TS_{obj}	3.5 (±0.6)	3.5 (±0.6)	3.6 (±0.5)	0.62
TS_{rad}	3.2 (±1.3)	2.7 (±1.5)	3.9 (±0.3)	0.04*
Union	31	18	13	n.s
Delayed union	5	2	3	n.s
Regular union	26	16	10	n.s
Period for union (months)	4.2 (±4.0)	3.5 (±3.2)	5.5 (±5.1)	0.44
Period for regular union (months)	2.5 (±1.2)	2.4 (±0.9)	2.8 (±1.7)	1.00
CCD% preop	+172 (±83)	+166 (±74)	+180 (±98)	0.92
CCD% follow-up	+34 (±36)	+32 (±32)	+36 (±43)	0.76

HPO hook plate osteosynthesis, *LPO* locking plate osteosynthesis, *CS* absolute Constant score, *OSS* Oxford shoulder score, *SSV* subjective shoulder value (%), TS_{tot} total Taft score, TS_{subj} subjective rating of Taft score; TS_{obj} Objective rating of Taft score, TS_{rad} radiological rating of Taft score, *CCD% preop. (follow-up)* percentage deviation of coracoclavicular distance of injured compared to healthy side as measured in preoperative (respectively follow-up) bilateral stress AP radiographs

*Statistical significance ($p < 0.05$) *n.s.* non-significant ($p > 0.05$)

Radiological outcome

Table 2 displays overall and cohort-specific (HPO versus LPO) clinical and radiological outcome measures. Figures 5 and 6 illustrate an exemplary LPO and HPO case, respectively. All except one fracture showed complete radiographical healing corresponding to a union rate of 96.9%. One patient experienced symptomatic non-union following HPO. Delayed union occurred in five patients (HPO: $n = 2$, LPO: $n = 3$). Mean time-period until radiographical proof of healing was 4.2 months (±4.0 months) for all patients and 2.5 months (±1.2 months) for the 26 patients with regular bone healing, respectively. Mean CCD decreased from a preoperative value of +172% (±82) to a follow-up value of +34% (±36) compared to the healthy, contralateral side. CCD values showed no significant differences between both treatment groups. Follow-up CCD increase was found to be >25% in 14 patients (Fig. 4). However, such persistent partial coracoclavicular instability did not significantly influence functional outcome measures.

Complications

Table 3 lists overall and cohort-specific (LPO versus HPO) complications. We noted non-union in one, delayed union in five, peri-implant fracture in one, screw misplacement with intra-articular ACJ positioning in one, radiographical follow-up proof of persistent acromial osteolysis in five and posttraumatic ACJ arthrosis in nine patients (Fig. 7). A total of 16 patients (50.0%) experienced complications. Overall prevalence of complications was significantly higher in the HPO cohort (HPO: $n = 17$, LPO: $n = 6$; $p = 0.014$). Also, prevalence of posttraumatic radiographic ACJ arthrosis was significantly ($p = 0.044$) higher in the HPO cohort. Only one HPO patient with posttraumatic ACJ arthrosis showed mild clinical symptoms and did not require secondary surgery. One patient was diagnosed with a peri-implant fracture 6 weeks after surgery at routine follow-up examination without any history of trauma. The peri-implant fracture ran transversely through the medial plate hole carrying a locking screw and caused an angulation of the clavicle in the coronar plane. The fracture configuration was consistent with biomechanical stress rising (overload) at the medial end of the osteosynthesis. The patient underwent revision surgery with a longer clavicular hook locking plate. The one patient with a symptomatic non-union declined revision surgery since complaints were tolerable. Patients exhibiting posttraumatic ACJ arthrosis achieved a significantly ($p = 0.001$) lower mean follow-up TS due to a significant ($p < 0.001$) decrease of radiological Taft subscores. Other observed complications did not affect clinical outcome significantly. Heterotopic ossifications in the coracoclavicular region were present in 12 patients (37.5%) ($n = 9$ HP, $n = 3$ LP; $p = 0.21$) and did not influence functional outcome measures.

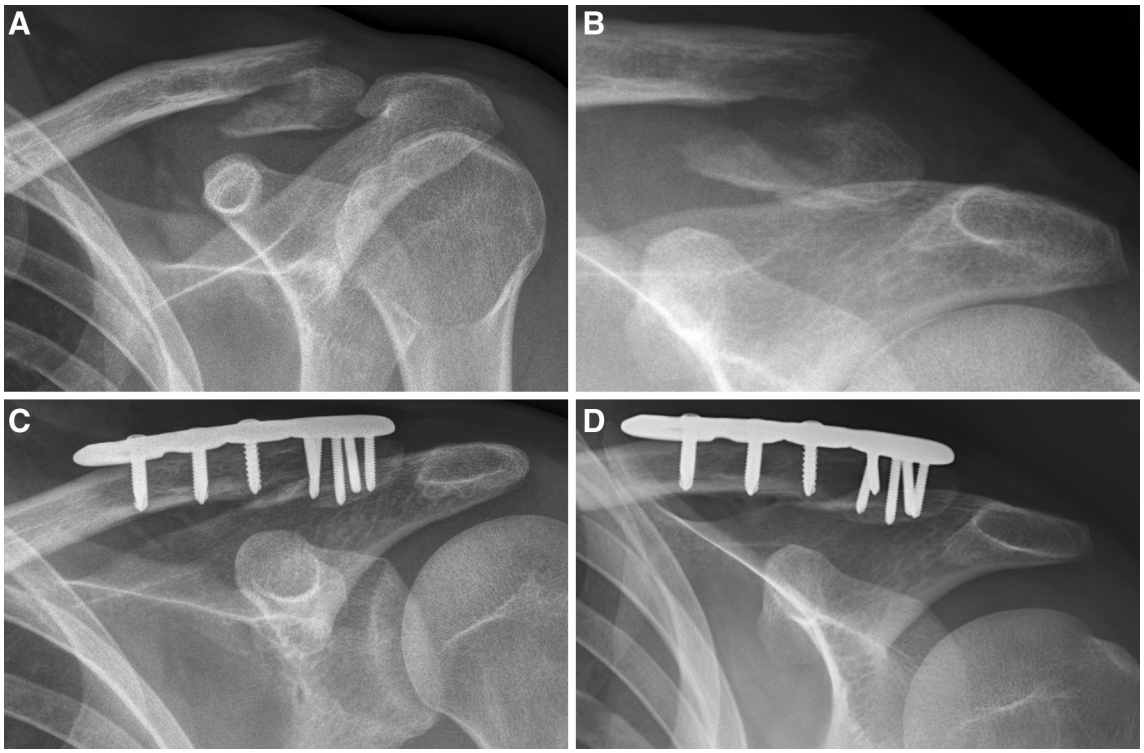

Fig. 5 Example of LPO of a Neer IIB fracture. anterior–posterior view without weight (**a**), anterior–posterior stress radiography with 10 kg vertical loading (**b**), anterior–posterior view of consolidated fracture without weight (**c**), follow-up anterior–posterior stress radiography with 10 kg vertical loading shows full restoration of coracoclavicular stability (**d**)

Discussion

Shin et al. [27] showed that isolated LPO of Neer II fractures without coracoclavicular stabilization only partially restores coracoclavicular stability. Mean CCD remained increased by 10% with a tendency of greater coracoclavicular instability for the subgroup of type IIB fractures. However, validity of CCD measurement is considerably limited, since CCD differences were measured at rest on plain radiographs without weight loading. In this context, we present the first study comparing efficacy of LPO versus HPO by means of preoperative and follow-up stress radiographs. Contrary to our hypothesis, HPO did not recreate CCD more effectively and LPO. Mean follow-up CCD remained increased by 34% compared to the healthy, contralateral side. There were no significant differences between both treatment groups (HPO versus LPO). Shin et al. [27] did not observe inferior subjective and objective functional outcomes in patients with persistent partial coracoclavicular instability. Accordingly, present study did not prove inferior functional outcomes in patients with a follow-up CCD increase of >25%. However, both studies are likely to be underpowered to allow for a conclusive assessment of clinical relevance of persistent coracoclavicular instability in vertically unstable lateral clavicle fractures.

LPO of Neer type II fractures achieves high rates of union ranging from 94 to 100% following [1, 2, 8, 15, 18, 27, 31, 32]. Consistently, we did not observe any non-union in the LPO group. However, prolonged and delayed healing may complicate both non-operative and operative treatment of unstable lateral clavicle fractures [23]. Only few authors stated time periods required for bone healing and no study differentiated between Neer IIA and IIB fractures [2, 18, 27, 32]. Bone healing is supposed to require mean periods of 2.9–4.1 months for the entirety of type II fractures [18, 27, 32], but might be prolonged for the subgroup of Neer IIB fractures. In our study, mean time-period until union was 4.2 months. Five patients (16%) showed delayed healing (>6 months). Prolonged and delayed union equally occurred in the HPO and LPO cohort. In this context, future studies should evaluate, whether persistent coracoclavicular instability causatively contributes to prolonged or delayed healing of Neer IIB fractures, and how the type of osteosynthesis influences healing behaviour.

Literature reports a large spectrum and spread of adverse events and complications following HPO of Neer II fractures [8, 10, 11, 14, 15, 21, 24, 28, 30]. Though, the lack of a uniform definition aggravates inter-study comparisons. Zhang et al. [32] analysed results of HPO and LPO of type II fractures. Functional outcomes were equal, but the

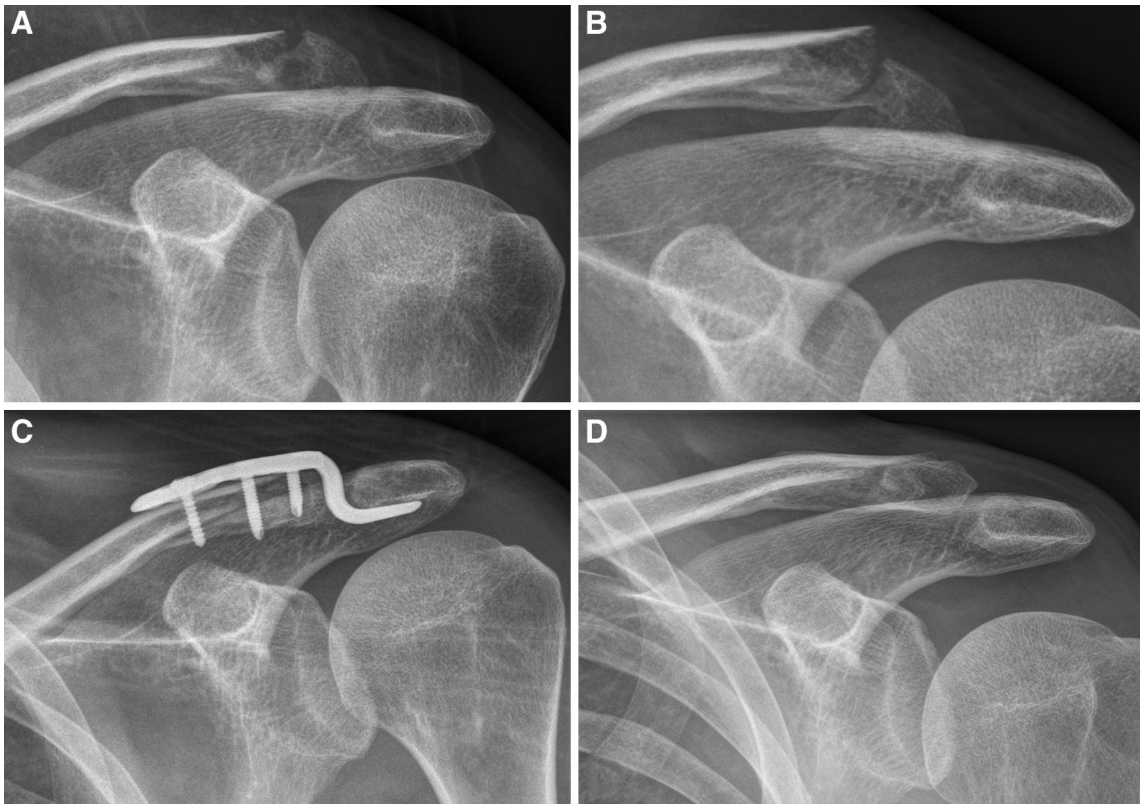

Fig. 6 Example of HPO of a Neer IIB fracture. Anterior–posterior view without weight (**a**), anterior–posterior stress radiography with 10 kg vertical loading (**b**), anterior–posterior view of consolidated fracture without weight (**c**), follow-up anterior–posterior stress radiography with 10 kg vertical loading shows partial restoration of coracoclavicular stability (**d**)

Table 3 Overall and cohort-specific complications

	Total	HPO	LPO	*p*
Patients	32	19	13	
Patients (%) with complications	16 (50.0%)	12 (63.2%)	4 (30.8%)	0.07
Overall complications	22	17	5	0.02*
Non-union	1 (3.1%)	1 (5.3%)	0	–
Delayed union	5 (15.6%)	2 (10.5%)	3 (23.1%)	0.34
Peri-implant fracture	1 (3.1%)	1 (5.3%)	0	–
Screw misplacement	1 (3.1%)	0	1 (7.7%)	–
Acromial osteolysis at follow-up	5 (15.6%)	5 (26.3%)	0	0.04*
Posttraumatic ACJ arthrosis	9 (28.1%)	8 (42.1%)*	1 (7.7%)	0.03*

HPO hook plate osteosynthesis, *LPO* locking plate osteosynthesis, *ACJ* acromioclavicular joint

*Statistical significance ($p < 0.05$)

rate of complications was significantly higher in the HPO group (23.3 versus 5.6%). In a systematic review on type II fractures, 66 of 162 patients (40.7%) treated with HPO experienced complications [23]. These findings cannot be directly compared to ours, since we only included type IIB fractures. Twelve of 19 HPO patients (63.2%) experienced complications, and the prevalence of overall complications was significantly higher compared to the LPO group. The majority (13/17) of HPO complications could be regarded as implant-specific ones, e.g. acromial osteolysis and posttraumatic ACJ arthrosis. In this context, persistent coracoclavicular instability and prolonged or delayed healing might promote hook plate-specific complications. In contrast to isolated ACJ dislocations, the hook plate for treatment of lateral clavicle fracture has to be left in place for a longer time-period until definite fracture consolidation

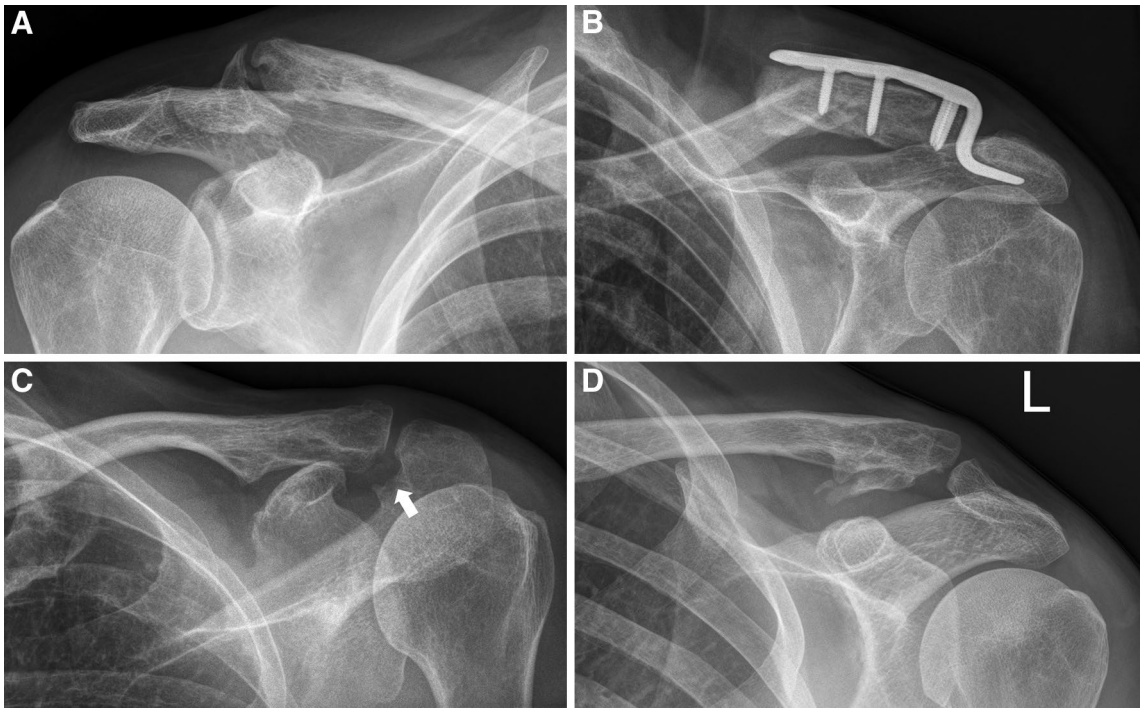

Fig. 7 Exemplary complications following HPO of Neer IIB fractures. Non-union (**a**), medial peri-implant stress fracture (**b**), acromial osteolysis (*white arrow*) detected at follow-up (**c**), heterotopic ossification and posttraumatic ACJ arthrosis (**d**)

has occurred. This prolonged stay of the hook plate (mean of 4.7 months in our study) appears to effect a higher rate of acromial osteolysis as well as ACJ arthrosis compared to non ACJ-spanning methods of osteosynthesis possibly caused by micromotions of the implant around the ACJ (Table 3). We did not detect any other cohort-specific profile differences that could have explained the higher rate of ACJ arthrosis (Table 1).

We observed two (6.3%) major complications such as symptomatic non-union and medial peri-implant fracture. Klein et al. [15] noted medial peri-implant fractures in 3/22 patients (13.6%) following acute and delayed HPO of type II fractures. Peri-implant fracture usually occurs as a result of biomechanical stress rising at the medial end of the osteosynthesis (Fig. 7). Clinical data suggest, that LPO with locking fixation of the lateral fragment improves load sharing and reduces the risk of peri-implant stress fractures [1, 2, 8, 13, 17, 18, 20, 32]. Even though, singular cases of peri-implant fractures or implant failures have been reported for LPO without coracoclavicular stabilization [1, 17]. Modern techniques of osteosynthesis include arthroscopic, arthroscopically assisted and mini-open procedures of coracoclavicular stabilization [16, 19, 22, 26]. Since preliminary clinical results did not report stress-related implant complications so far, such additional coracoclavicular stabilization could further enhance biomechanical stability and reduce stress rising [12, 17, 20]. However, the spectrum and limits of indications have not yet been conclusively defined and mid- to long-term results are pending.

Clinical outcomes of present study comply with the literature [2, 8, 10, 18, 25, 27, 28, 32]. In spite of the considerably high rate of complications and delayed unions, follow-up shoulder functions were graded as excellent or good in all but two patients (94%). This apparent contradiction is well explained by the rigorous definition and precise analysis of complications. In addition, the vast majority were minor complications without influence on the end result. CS, OSS and SSV showed a trend to superior results in the LPO cohort, but significant differences could only be detected by means of the ACJ-specific TS. HPO patients achieved significantly inferior TS due to a higher prevalence of posttraumatic ACJ arthrosis. Table 4 displays an exemplary overview on outcome and complications of different operative treatment modalities.

This study has some limitations. First of all, present study was based on a retrospective database research. Strict inclusion and exclusion criteria caused a limited case number but enhanced conclusiveness and validity of this comparative cohort study. Current findings indicate a relevant proportion of concomitant intra-articular glenohumeral injuries [3]. However, no patient had to undergo secondary surgery or showed clinical signs of associated injuries throughout the follow-up period. Choice of implants was not randomised and solely depended on the surgeon's

Table 4 Overview on outcome and complications of operative treatment modalities

References	Treatment	*N*	Type	Age (years)	FU (months)	Outcome	CCD% FU	Complications
Shin et al. [24]	Precontoured superior locking plate without cc-stabilization or -reconstruction	16	IIB	41.6 (29–78)	25 (24–27)	CS: 88.9 (78–95)	+11% (without weights)	1× shoulder stiffness 5× implant removal due to cosmesis (prominence)
Schliemann et al. [22]	Superior locking plate with flip button cc-stabilization	14	IIB	38 (22–54)	38 (8–75)	CS: 93.5 (85–100) TS: 11.2 (10–12)	+14% (with 5 kg weights)	3× heterotopic ossification 3× implant removal due to local irritation 1× imminent skin perforation
Zhang et al. [28]	Superior locking plate without cc-stabilization or -reconstruction	36	II	42.5 (±10.7)	28.6 (±6.2)	CS: 95.5 (±5.9)	N.e	1× non-union 1× loss of reduction
	Hook plate	30	II	41.1 (±10.3)	27.7 (±6.1)	CS: 93.3 (±8.1)	N.e	2× non-union 1× hardware failure 2× loss of reduction 3× symptomatic hardware
Loriaut et al. [16]	Arthroscopic double button fixation	21	IIB	33 (18–67)	35 (24–51)	CS: 94.8 (62–100)	N.e	1× non-union 1× hardware failure 1× shoulder stiffness 1× symptomatic posttraumatic ACJ arthritis 2× heterotopic ossification
Current study	Locking plate without cc-stabilization or -reconstruction (LPO)	13	IIB	43.7 (±13.7)	53.3 (±19.6)	CS: 92.2 (±4.2) TS: 11.1 (±1.3)	+36% (with 10 kg weights)	3× delayed union 1× screw misplacement 4× heterotopic ossification
	Hook plate (HPO)	19	IIB	44.3 (±14.9)	54.9 (±19.8)	CS: 88.7 (±8.8) TS: 9.5 (±1.5)*	+32% (with 10 kg weights)	1× non-union 2× delayed union 1× peri-implant fracture 5× acromial osteolysis 1× symptomatic posttraumatic ACJ arthritis 9× heterotopic ossification

FU follow-up, *CCD% FU* percentage deviation of coracoclavicular distance of injured compared to healthy side as measured in follow-up radiographs, *cc* coracoclavicular, *CS* Constant score, *TS* Taft score, *N.e*. not evaluated

*Statistical significance ($p < 0.05$)

personal preference. Though, both cohort profiles were statistically comparable with respect to all relevant influencing factors (Table 1). Therefore, we may exclude any substantial selection or performance bias. Bilateral AP stress views might not guarantee perfectly identical projections when comparing different patients and different time points. Though, we did not observe relevant discrepancies of projection. All CCD measurements relied on comparison to the contralateral side, hereby minimizing the effect of projection variation. Thus, the study employed the current standard of clinical routine diagnostics with the best achievable accuracy. At follow-up, 3/13 LPO implants were still in situ compared to none in the HPO group. None of these three patients had implant-associated complaints, and therefore, denied plate removal. We suspected no relevant influence on follow-up CCD measurements, since all three

fractures showed complete radiographical healing and LPO implants were non AC-spanning.

Conclusions

Both LPO and HPO reliably achieved bone union, but only partially restored coracoclavicular stability. Contrary to our hypothesis, HPO did not recreate CCD more effectively than LPO. However, persistent partial coracoclavicular instability was not associated with inferior functional outcomes. Delayed bone union occurred in a relevant proportion (16%) of patients but was not related to the type of osteosynthesis. Precise analysis of adverse events revealed a considerably high-rate of overall complications. Half of patients experienced complications, with a prevalence being significantly higher in the HPO cohort. Though, clinical follow-up examinations showed excellent or good objective and subjective functional results in the vast majority of patients (94%). Clinical relevance of persistent coracoclavicular instability requires further investigations. Future studies should also examine, whether LPO combined with minimal-invasive coracoclavicular stabilization may improve restoration of coracoclavicular stability, accelerate healing and lower complication rates.

Compliance with ethical standards

Conflict of interest None of the above authors declare to have received any source of support in the form of grants, equipment, or other items. The authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

Institutional Review Board (IRB) or Ethical Committee approval Ethical Committee, Albert-Ludwigs-University Freiburg, Engelberger Strasse 21, 79106 Freiburg; Study number 397/15.

References

1. Andersen JR, Willis MP, Nelson R, Mighell MA (2011) Precontoured superior locked plating of distal clavicle fractures: a new strategy. Clin Orthop Relat Res 469(12):3344–3350. doi:10.1007/s11999-011-2009-5
2. Beirer M, Siebenlist S, Cronlein M, Postl L, Huber-Wagner S, Biberthaler P, Kirchhoff C (2014) Clinical and radiological outcome following treatment of displaced lateral clavicle fractures using a locking compression plate with lateral extension: a prospective study. BMC Musculoskelet Disord 15:380. doi:10.1186/1471-2474-15-380
3. Beirer M, Zyskowski M, Cronlein M, Pforringer D, Schmitt-Sody M, Sandmann G, Huber-Wagner S, Biberthaler P, Kirchhoff C (2015) Concomitant intra-articular glenohumeral injuries in displaced fractures of the lateral clavicle. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-015-3875-2
4. Boehm D (2002) Scores. In: Gohlke F, Hedtmann A (eds) Schulter: Das Standardwerk für Klinik und Praxis. Thieme, Stuttgart, pp 98–104
5. Constant CR, Murley AH (1987) A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res (214):160–164
6. Craig E (1990) Fractures of the clavicle. In: Rockwood CA, Matsen FA (eds) The shoulder. WB Saunders, Philadelphia, pp 367–412
7. Dawson J, Fitzpatrick R, Carr A (1996) Questionnaire on the perceptions of patients about shoulder surgery. J Bone Jt Surg Br 78(4):593–600
8. Fleming MA, Dachs R, Maqungo S, du Plessis JP, Vrettos BC, Roche SJ (2015) Angular stable fixation of displaced distal-third clavicle fractures with superior precontoured locking plates. J Shoulder Elbow Surg 24(5):700–704. doi:10.1016/j.jse.2014.09.024
9. Gilbart MK, Gerber C (2007) Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg 16(6):717–721. doi:10.1016/j.jse.2007.02.123
10. Good DW, Lui DF, Leonard M, Morris S, McElwain JP (2012) Clavicle hook plate fixation for displaced lateral-third clavicle fractures (Neer type II): a functional outcome study. J Shoulder Elbow Surg 21(8):1045–1048. doi:10.1016/j.jse.2011.07.020
11. Haidar SG, Krishnan KM, Deshmukh SC (2006) Hook plate fixation for type II fractures of the lateral end of the clavicle. J Shoulder Elbow Surg 15(4):419–423. doi:10.1016/j.jse.2005.11.012
12. Hohmann E, Hansen T, Tetsworth K (2012) Treatment of Neer type II fractures of the lateral clavicle using distal radius locking plates combined with TightRope augmentation of the coracoclavicular ligaments. Arch Orthop Trauma Surg 132(10):1415–1421. doi:10.1007/s00402-012-1570-z
13. Kalamaras M, Cutbush K, Robinson M (2008) A method for internal fixation of unstable distal clavicle fractures: early observations using a new technique. J Shoulder Elbow Surg 17(1):60–62. doi:10.1016/j.jse.2007.04.012
14. Kashii M, Inui H, Yamamoto K (2006) Surgical treatment of distal clavicle fractures using the clavicular hook plate. Clin Orthop Relat Res 447:158–164. doi:10.1097/01.blo.0000203469.66055.6a
15. Klein SM, Badman BL, Keating CJ, Devinney DS, Frankle MA, Mighell MA (2010) Results of surgical treatment for unstable distal clavicular fractures. J Shoulder Elbow Surg 19(7):1049–1055. doi:10.1016/j.jse.2009.11.056
16. Kraus N, Stein V, Gerhardt C, Scheibel M (2015) Arthroscopically assisted stabilization of displaced lateral clavicle fractures with coracoclavicular instability. Arch Orthop Trauma Surg 135(9):1283–1290. doi:10.1007/s00402-015-2271-1
17. Largo RD, Rudin MA, Hotz TK, Valderrabano V, Kach KK (2011) Anatomic reconstruction of unstable lateral clavicular fractures. J Trauma 71(5):1348–1351. doi:10.1097/TA.0b013e3182095dd1
18. Lee SK, Lee JW, Song DG, Choy WS (2013) Precontoured locking plate fixation for displaced lateral clavicle fractures. Orthopedics 36(6):801–807. doi:10.3928/01477447-20130523-28
19. Loriaut P, Moreau PE, Dallaudiere B, Pelissier A, Vu HD, Massin P, Boyer P (2015) Outcome of arthroscopic treatment for displaced lateral clavicle fractures using a double button device. Knee Surg Sports Traumatol Arthrosc 23(5):1429–1433. doi:10.1007/s00167-013-2772-9
20. Martetschlager F, Kraus TM, Schiele CS, Sandmann G, Siebenlist S, Braun KF, Stockle U, Freude T, Neumaier M (2013) Treatment for unstable distal clavicle fractures (Neer 2) with locking T-plate and additional PDS cerclage. Knee Surg Sports Traumatol Arthrosc 21(5):1189–1194. doi:10.1007/s00167-012-2089-0

21. Meda PV, Machani B, Sinopidis C, Braithwaite I, Brownson P, Frostick SP (2006) Clavicular hook plate for lateral end fractures: a prospective study. Injury 37(3):277–283. doi:10.1016/j.injury.2005.10.017
22. Motta P, Bruno L, Maderni A, Tosco P, Mariotti U (2014) Acute lateral dislocated clavicular fractures: arthroscopic stabilization with TightRope. J Shoulder Elbow Surg 23(3):e47–e52. doi:10.1016/j.jse.2013.05.016
23. Oh JH, Kim SH, Lee JH, Shin SH, Gong HS (2011) Treatment of distal clavicle fracture: a systematic review of treatment modalities in 425 fractures. Arch Orthop Trauma Surg 131(4):525–533. doi:10.1007/s00402-010-1196-y
24. Renger RJ, Roukema GR, Reurings JC, Raams PM, Font J, Verleisdonk EJ (2009) The clavicle hook plate for Neer type II lateral clavicle fractures. J Orthop Trauma 23(8):570–574. doi:10.1097/BOT.0b013e318193d878
25. Schliemann B, Rosslenbroich SB, Schneider KN, Petersen W, Raschke MJ, Weimann A (2013) Surgical treatment of vertically unstable lateral clavicle fractures (Neer 2b) with locked plate fixation and coracoclavicular ligament reconstruction. Arch Orthop Trauma Surg 133(7):935–939. doi:10.1007/s00402-013-1737-2
26. Schwarting T, Lechler P, Bockmann B, Debus F, Ziring E, Frink M (2015) The benefit of arthroscopically assisted therapy for concomitant glenohumeral injuries in patients with unstable lateral clavicle fractures. Knee Surg Sports Traumatol Arthrosc. doi:10.1007/s00167-015-3909-9
27. Shin SJ, Ko YW, Lee J, Park MG (2015) Use of plate fixation without coracoclavicular ligament augmentation for unstable distal clavicle fractures. J Shoulder Elbow Surg. doi:10.1016/j.jse.2015.10.016
28. Stegeman SA, Nacak H, Huvenaars KH, Stijnen T, Krijnen P, Schipper IB (2013) Surgical treatment of Neer type-II fractures of the distal clavicle: a meta-analysis. Acta Orthop 84(2):184–190. doi:10.3109/17453674.2013.786637
29. Taft TN, Wilson FC, Oglesby JW (1987) Dislocation of the acromioclavicular joint. An end-result study. J Bone Jt Surg Am 69(7):1045–1051
30. Tiren D, van Bemmel AJ, Swank DJ, van der Linden FM (2012) Hook plate fixation of acute displaced lateral clavicle fractures: mid-term results and a brief literature overview. J Orthop Surg Res 7:2. doi:10.1186/1749-799X-7-2
31. Tiren D, Vroemen JP (2013) Superior clavicle plate with lateral extension for displaced lateral clavicle fractures: a prospective study. J Orthop Traumatol 14(2):115–120. doi:10.1007/s10195-013-0228-0
32. Zhang C, Huang J, Luo Y, Sun H (2014) Comparison of the efficacy of a distal clavicular locking plate versus a clavicular hook plate in the treatment of unstable distal clavicle fractures and a systematic literature review. Int Orthop 38(7):1461–1468. doi:10.1007/s00264-014-2340-z