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Minimally invasive plate osteosynthesis for clavicle fractures

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Abstract

Objective: Treatment of comminuted clavicle shaft fractures with minimally invasive plate osteosynthesis (MIPO).
Indications: Multifragmentary (≥ 2 intermediate fragments) clavicle shaft fractures with no need for anatomical reduction (AO 15.2B and 15.2C). Even simple fractures (AO 15.2A) with significant soft tissue injuries Tscherne grade I–III are suitable.
Contraindications: Medial or lateral clavicle fractures as well as simple fracture pattern where anatomical reduction is indispensable.
Surgical technique: Short incision over the medial and lateral end of the main fracture fragments. Either medial or lateral epiperosteal plate insertion. Under image intensifier guidance, the plate is centered either superior or anteroinferior on the clavicle and fixed with a compression wire temporarily (alternatively by a cortical screw) in one of the most lateral holes. Fracture reduction (axis, length, and rotation) over the plate and preliminary fixation medially. After correct reduction has been achieved, further cortical screws and/or locking head screws can be inserted (lag before locking screws). Relative stability is achieved by applying a bridging technique.
Postoperative management: No immobilization is needed. Patients are encouraged to perform functional rehabilitation with active and passive physical therapy. Loading is increased according to radiological signs of bony consolidation.
Results: In a retrospective evaluation from 2001–2021, 1128 clavicle osteosyntheses were performed, of which 908 (80.5%) were treated with plate osteosynthesis and 220 (19.5%) with titanium elastic nail (TEN). Of the 908 plate osteosyntheses, 43 (4.7%) were performed with the MIPO approach. Finally, 42 patients (35 men and 7 women; mean age of 44 ± 15 years) with 43 clavicle shaft fractures were analyzed. The operation was accomplished in 63 ± 28 min, and average fluoroscopy time was 45 ± 42 s. A collective of 27 patients could be evaluated after a median follow-up of 14 months (range 1–51 months). In all, 26 fractures healed in a timely manner. In 1 patient a pseudarthrosis occurred which was treated with re-osteosynthesis and cancellous bone grafting in an open technique. Another patient revealed a wound complication with need of operative wound revision 6 weeks after the index surgery. Further postoperative course was uneventful in both patients. All were pain-free and able to return to work. After an average of 17 ± 8 months, 18 hardware removals (66.7%) were performed.

Keywords
Functional alignment · Radiation exposure · Closed reduction · Soft tissue injuries · Multifragmentary fractures

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Introduction

The clavicle is one of the key elements of the shoulder girdle and is responsible for transmission of forces from the upper extremity to the axial skeleton. Fractures of the clavicle are common injuries and represent up to 4% of all fractures [1–3]. Midshaft clavicle fractures (MCFs) have the highest incidence and account for approximately 80% of all clavicle fractures [3, 4]. Nearly half of these are displaced midshaft clavicle fractures (DMCFs) [5]. Historically, the vast majority of these DMCFs have been treated conservatively. However, several authors noted unsatisfactory outcomes after nonoperative treatment with higher nonunion rates and increased functional deficits [6–10]. Therefore, during the last 20 years a paradigm shift towards operative management has occurred.

Based on the current literature in 2019 Frima et al. [11] published a treatment algorithm for clavicle fractures in adults. MCFs should therefore be operated on in case of (1) displacement of > 1 shaft width, (2) open fracture, (3) neurovascular injury, (4) floating shoulder, (5) polytrauma (concomitant serial rib fractures), and (6) pathological fractures. Simple fracture patterns (AO 15.2A) are suitable for intramedullary fixation, whereas wedge (AO 15.2B) and comminuted fractures (AO 15.2C) should be treated with a (locking) plate. In more or less simple fracture patterns (AO 15.2A and 15.2B) where an anatomical reduction is feasible, the standard operative treatment is still open reduction followed by internal fixation (ORIF). In contrast, in comminuted fractures (≥ 2 intermediate fragments), which are often associated with high energy trauma, anatomic reduction should not be attempted. In these multifragment fracture patterns, stabilization with a (locking) plate using a minimally invasive technique (minimally invasive plate osteosynthesis [MIPO]) provides relative stability and follows the reduction goals of functional alignment (correct length, axes, and rotation). Minimally invasive surgery protects vascularity of fracture fragments and preserves fracture hematoma as well as the already compromised soft tissues around the fracture site. Since this is a demanding technique, the possible disadvantages associated with it, such as increased radiation exposure or prolonged operative time, can be well accepted in favor of reduced wound healing disorders or nonunion. The purpose of this study is to present the surgical strategy in detail.

Surgical principles and objective

A MIPO approach to the clavicle is only recommended for the treatment of complex, comminuted clavicle fractures which cannot be reduced anatomically or in case of severe soft tissue damage over the fracture zone. Following minimally invasive principles, the fracture zone is bridged with a long plate under correct length, axis, and rotation. A plate-span ratio 2–3:1, which means that the length of the plate should be two to three times to the length of the fracture zone, and two to three bicortical screws (cortical or locking head screws) on each side of the fracture are required for balanced fixation. With the recently introduced VA-LCP® 2.7 clavicle plate system (DePuy Synthes, Switzerland), it is necessary to insert a minimum of four 2.7 mm screws per main fracture fragment.

Aiming for an anteroinferior plate position, it must be realized that the clavicle is a straight bone in this plane. Therefore, the plate must be bent only in one plane. Based on individual anatomical condition, the clavicle is curved concave on the lateral and slightly convex on the medial end (vertical S-shape). Contouring of the plate can be performed preoperatively using an artificial bone model, or intraoperatively (in case of an intact contralateral clavicle as a reference by manual palpation or image intensification).

Advantages

- Less soft tissue damage without extensile incisions resulting in muscular or subcutaneous flaps
- No devascularization of fracture fragments
- Fewer wound healing problems
- Rapid recovery
- Shortened length of hospital stay

Disadvantages

- Minimally invasive instruments and special surgical techniques are required
- Technical demanding
- Increased radiation exposure
- Limited control of fracture reduction

Indications

- Multifragmentary (≥ 2 intermediate fragments) fracture pattern with no need for anatomical reduction (AO 15.2B and 15.2C)
- Displacement of ≥ 1 shaft width
- Deep skin abrasions at the site of the planned incision (Tscherne grade II–III)

Contraindications

- Simple fracture pattern (AO 15.2A) with uninjured soft tissues
- Truly medial or lateral clavicle fractures (AO 15.1 and 15.3)
- Intra-articular fractures
- Open fractures
- Symptomatic mal-/nonunions
- Pathological fractures
- Clavicle fractures with concomitant neurovascular injury

Patient information

- General surgical risks
- Mal- or nonunion
- Tangential screw position with potentially loss of fixation
- Risk of vascular damage (subclavian artery/vein)
- Implant-related irritation
- Postoperative frozen shoulder
- Postoperative infection with further surgical interventions
- Hardware removal is usually suggested
- Immediate postoperative mobilization with no weight bearing

Preoperative work up

- Examination and documentation of the peripheral pulses and neurological findings
- X-ray films of the entire clavicle at different orthogonal views
- Perioperative intravenous antibiotic prophylaxis (e.g., 2000 mg cefazolin)
- Image intensifier

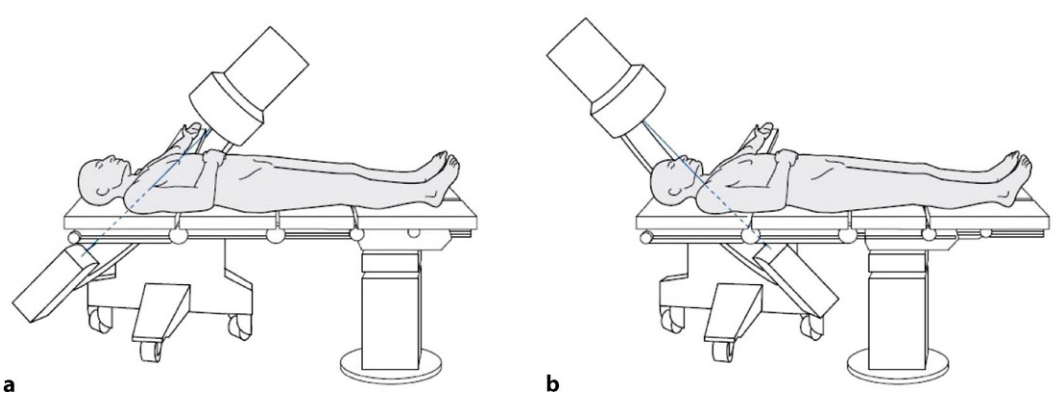

Fig. 1 ◀ Patient and image intensifier positioning. The clavicle must be analyzed in two different planes with a totally angulation of 90°. C-arm position enables a caudocranial (**a**) and craniocaudal view (**b**). ([16, Cases Clavicle: 11.2, page 166, Figure 11.2-2a–b]. Copyright AO Foundation, Switzerland with kind permission from the AO Foundation, Switzerland)

Instruments

- Basic surgical instruments
- Minimally invasive reduction instruments (DePuy Synthes)
- K-wires and small pointed reduction forceps
- LCP 3.5 or VA-LCP 2.7 clavicle system, adapted to the length of the fracture (DePuy Synthes)
- Locking head screws (2.7–3.5 mm, depending on size of implant dimension)
- Cortical screws (2.7–3.5 mm, depending on size of implant dimension)
- Plate bending instruments

Anesthesia and positioning

- General anesthesia
- Supine position on a radiolucent operating table (◘ **Fig. 1**)
- The image intensifier is placed to ensure visualization of the entire clavicle in two planes (anteroposterior [AP] caudocranial and AP craniocaudal)

Surgical technique

(◘ **Fig. 2**, **3**, **4**, **5**, **6**, **7** and **8**).

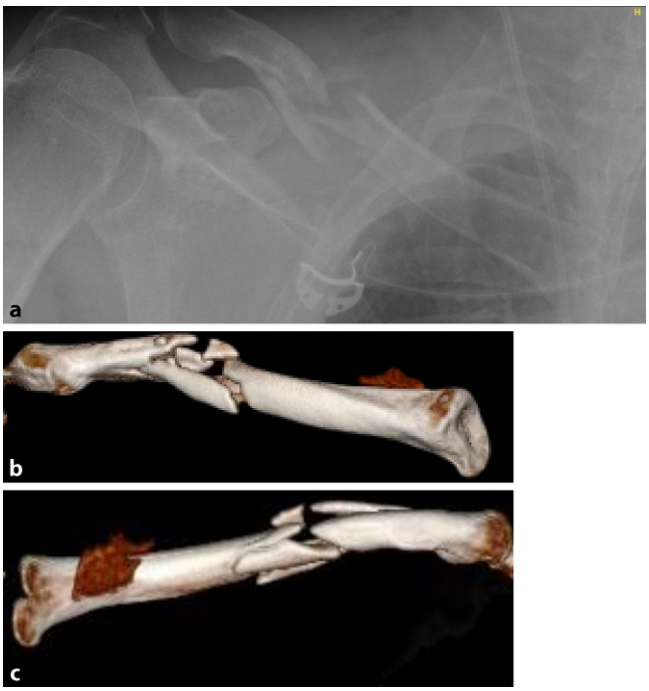

Fig. 2 ▲ The technique will be illustrated for a right comminuted clavicle fracture (AO 15.2C) with a superior plate position. X-ray (**a**) and three-dimensional (3D) computer tomographic (CT) reconstruction (**b**, **c**) show a multifragmentary clavicle fracture on the right side. The main medial and lateral fracture fragments have no cortical reads to each other

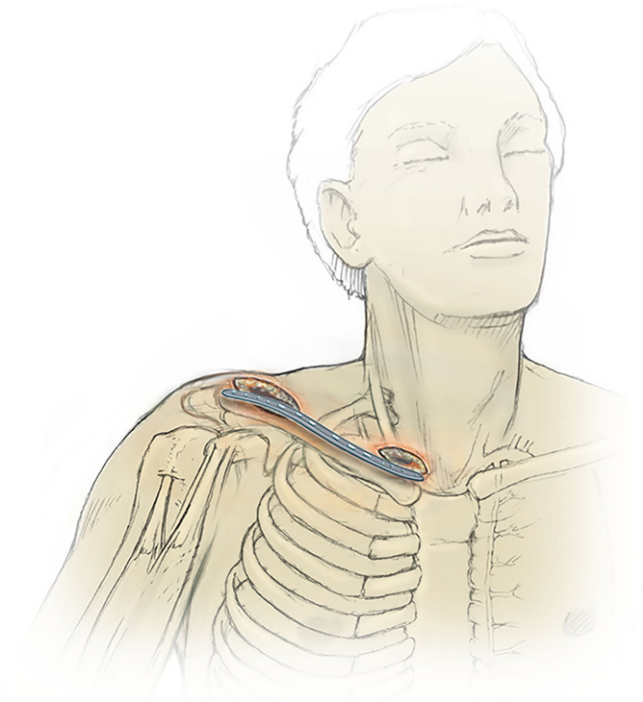

Fig. 3 ▲ According to the fracture pattern as well as the desired plate position and length, the skin incision is placed away from the fracture zone over the medial and lateral end of the main fracture fragments

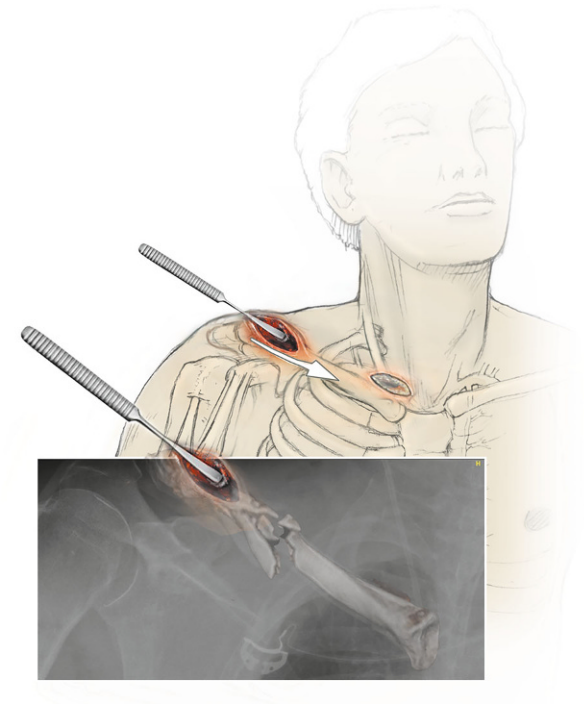

Fig. 4 ▲ Skin incision (2–3 cm) over the medial and lateral end of the main fracture fragments, respectively. Sharp dissection through the subcutaneous tissue until the periosteum is reached. Epiperosteal tunneling (either superior or anteroinferior depending on desired plate position) over the fracture zone with the aid of a raspatory. Afterwards, the plate can be inserted from the medial or lateral side easily

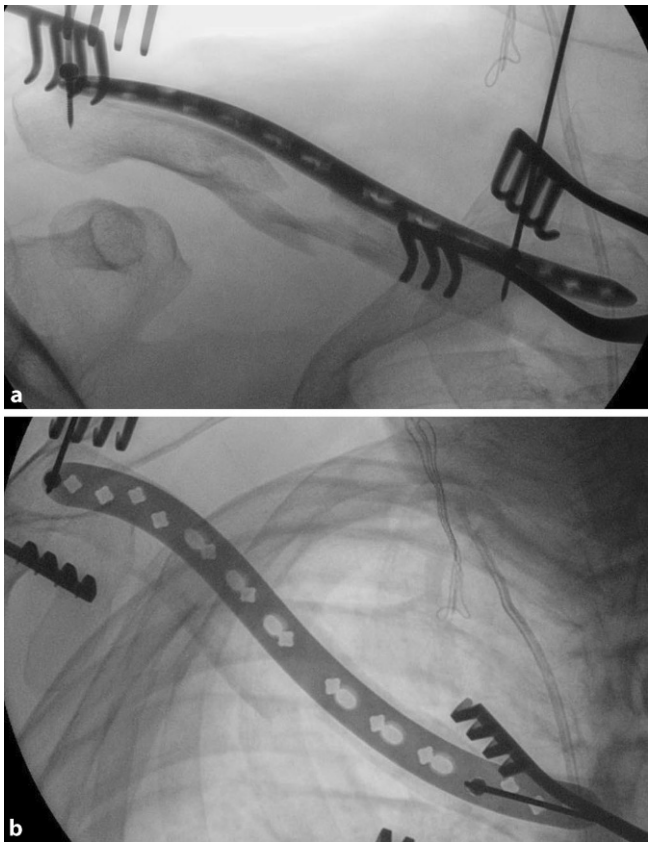

Fig. 5 ▲ After creating an epiperosteal tunnel, the anatomically preshaped plate (VA-LCP® 2.7 clavicle plate system, DePuy Synthes, Switzerland) can be inserted from lateral to medial or vice versa. Aided by the image intensifier the plate is centered on the clavicle. If the plate does not fit the anatomical conditions, it must be bent accordingly. However, care should be taken not to provoke any malpositioning. The plate is then fixed to the clavicle with a compression wire in one of the most lateral holes. Alternatively, a cortical screw can be used to attach the plate to the bone. The fracture can now be reduced indirectly over the plate. Length, rotation, and angulation must be addressed accordingly. Next, preliminary fixation of the plate is performed medially by insertion of another compression wire (alternatively cortical screw). Image intensification shows a well-aligned fracture and a satisfactory plate position in two planes (**a**, **b**). After correct reduction has been achieved, further cortical screws and/or locking head screws can be inserted (lag before lock)

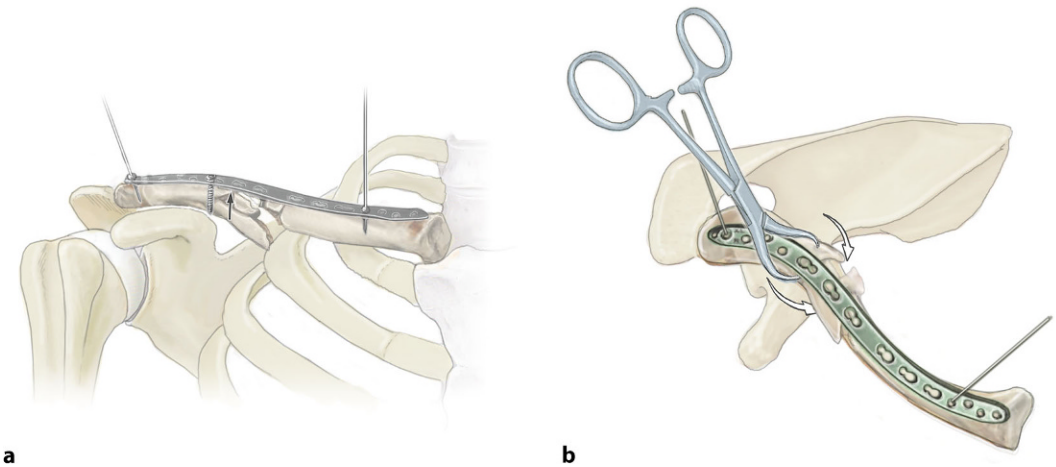

Fig. 6 ◀ In case of remaining angulation, a cortical screw can be inserted to approximate the bone to the plate (*arrow* in **a**). Angulation can also be achieved using reduction forceps (**b**)

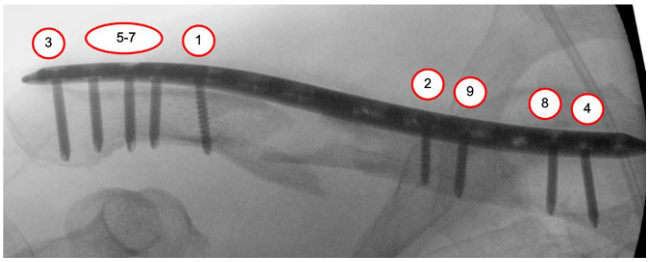

Fig. 7 ▲ Sequence of screw insertion. First, a cortex screw (*1* and *2*) is inserted on each side of the fracture zone. This approximates the bone to the anatomically preshaped plate. Any remaining angulation can now be addressed by the techniques described above (◘ **Fig. 6**). Once alignment is correct, the remaining locking head screws (*3*–*9*) are inserted

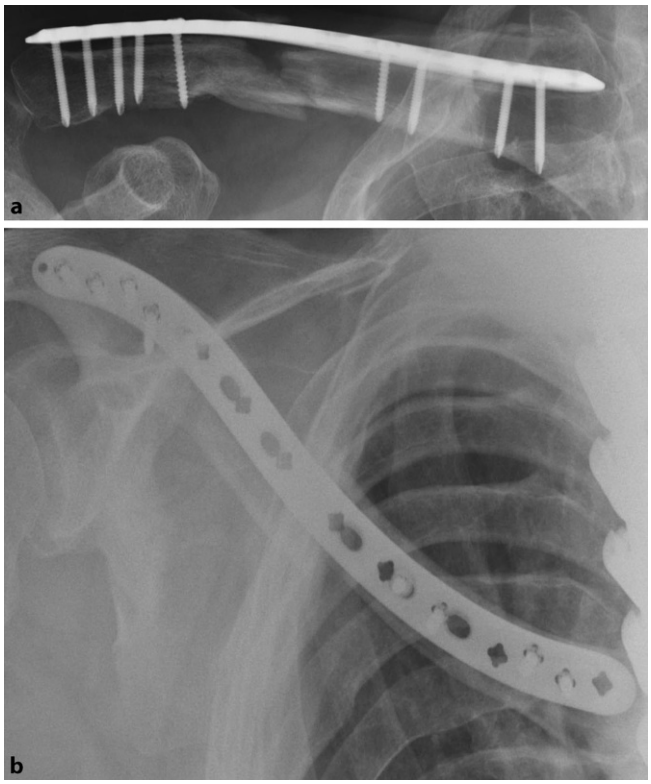

Fig. 8 ▲ Postoperative x-rays show correct alignment of the fracture in two planes (**a**, **b**). A balanced osteosynthesis with sufficient plate length and correct fixation on each side was performed

Case report

(◘ **Figs. 9**, **10**, **11** **and** **12**).

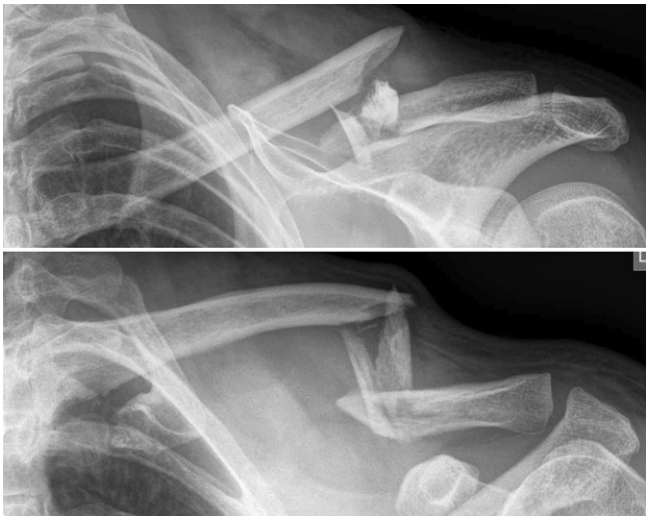

Fig. 9 ◄ A 33-year-old man sustained a comminuted clavicle shaft fracture after a motorbike accident

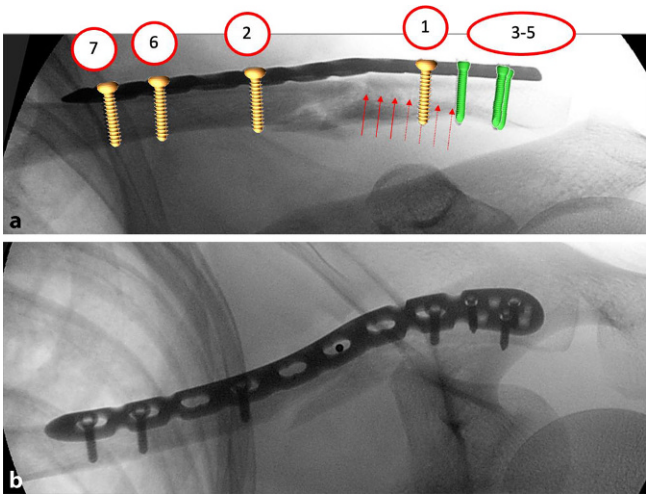

Fig. 10 ▲ A skin incision was made superior over the medial and lateral end of the clavicle. After epiperosteal tunneling over the fracture zone with the aid of a raspatory, the anatomical preshaped 2.7/3.5 mm LC superior clavicle plate© (DePuy Synthes, Switzerland) was inserted from lateral. The plate was then centered on the clavicle and subsequently a cortex screw (*1*) in a lag technique was inserted into the lateral fragment close to the fracture zone. This approximates the bone to the anatomically preshaped plate and moreover achieves interfragmentary compression in the fissural fracture extension into the main lateral fragment (**a**, *red arrows*). Another cortex screw was inserted into the medial fragment (*2*). Correct alignment (length, axes, and rotation) was checked under image intensification and sequential screw insertion using locking head screws (*3–5*) and cortical screws (*6, 7*) was performed (**b**)

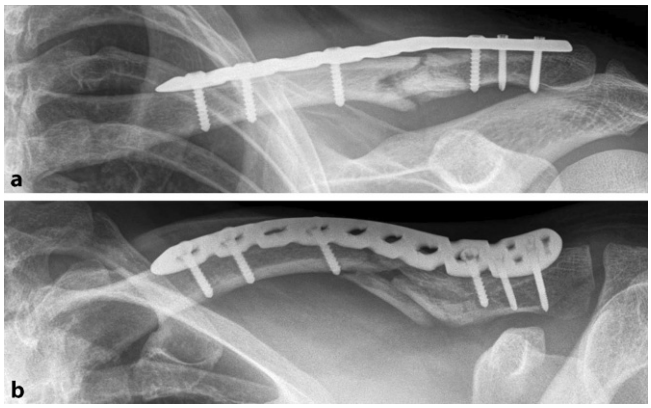

Fig. 11 ▲ Postoperative radiographs (**a**, **b**) demonstrating correct alignment. The fracture zone is bridged with a long plate and a balanced fixation was achieved

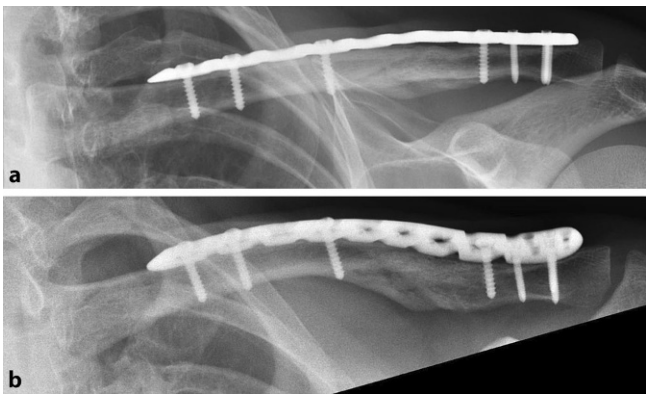

Fig. 12 ◀ Over a period of 10 months sufficient fracture healing with remodeling was demonstrated on x-rays (**a**, **b**)

Postoperative management

- Immediate active-assisted mobilization without limitation of range of motion or immobilization devices
- Weight-bearing is not allowed during the first 6 weeks until the first clinical and radiological follow-up
- Conventional radiographs are taken before discharge, after 6 weeks, 3 months, 6 months, and 1 year
- Implant removal is not performed routinely and only on patient's request

Errors, hazards, complications

- Malunion
- Nonunion
- Bleeding
- Iatrogenic neurovascular injury
- Implant failure

Results

From 2001–2021, 1128 clavicle osteosyntheses were performed, of which 908 (80.5%) were treated with plate osteosynthesis and 220 (19.5%) with titanium elastic nail (TEN). Of the 908 plate osteosyntheses, 43 (4.7%) were performed with the MIPO approach. Finally, 42 patients with 43 clavicle shaft fractures (one case with bilateral clavicle fractures) were treated at our trauma unit using the MIPO technique. The patients were on average 44 ± 15 years old, 83.3% were male, and none had had a prior clavicle injury. Of the 43 fractures, 34 (79.1%) were sports injuries, with ski ($n = 14$) being the most common, followed by bicycle ($n = 9$), motorbike accidents ($n = 7$), and 4 other sport-related injuries. Two open fractures (both Gustilo I°) and 41 closed fractures were noted (0° = 26; I° = 13, II° = 2 according to Oestern and Tscherne). In 7 patients (16.7%), the clavicle fractures were part of a polytrauma, defined as an Injury Severity Score (ISS) ≥ 16, whereas 14 patients (33.3%) did not reveal any relevant further injuries beside the clavicle fracture. In 19 patients (45.2%), serial rib fractures (defined as more than three consecutive rib fractures) were diagnosed and 10 patients (23.8%) presented with concomitant scapula neck fractures (i.e., floating shoulder). Based on the AO/OTA classification, most of the fractures could be categorized as type C injuries ($n = 26$), followed by A ($n = 9$) and B ($n = 8$).

The mean delay from trauma to surgery was 3 ± 5 days. In 20 patients (47.6%), definitive treatment was planned upon arrival at the emergency room, whereas in 21 patients (50%) the operative treatment was planned secondarily, after sling immobilization for a few days. In one patient

fracture treatment was performed after an initial conservative management had failed and a secondary fracture displacement was found on control radiographs 5 days after trauma.

The length of operation was 63 ± 28 min, and average fluoroscopy time was 45 ± 42 s. In 33 cases (76.7%), an anteroinferior plate position was chosen, using a standard 3.5 LCP® (De Puy Synthes, Switzerland). In 10 cases (23.3%) a superior plate position was used, of which an anatomical preshaped LCP® (De Puy Synthes, Switzerland) was chosen in 9 of the 10 patients, while one patient was treated with a bended standard 3.5 LCP® (De Puy Synthes, Switzerland). We did not use the superior placed, preshaped clavicle plates before 2012, which became mostly the standard of care for clavicle shaft fractures in our trauma unit shortly afterwards. Mean length of hospitalization was 4 ± 3 days, excluding the severely polytraumatized patients, and patients with a clavicular fracture only, without any further injuries (i.e., rib fractures or scapular fractures), mean length of hospitalization was 2 ± 1 days. Surgery was successfully completed without intraoperative complications in any of the patients. There were also no complications relating to the clavicle injury observed during the hospitalization in any of the patients.

Of the 43 fractures (62.8%), 27 could be evaluated after a median follow-up of 14 months (range 1–51 months). Reasons for dropouts were residence distant to the trauma unit in 13 patients. Two dropouts occurred for unknown reasons, and the most recent patient is expected to meet his outpatient appointments soon after drafting this manuscript.

Of 27 followed-up fractures, 26 healed with radiographically significant callus formation within the first 3 months after operation. In 1 patient, pseudarthrosis and following hardware fracture occurred 2 years after fracture treatment. An open technique was chosen for re-osteosynthesis and cancellous bone grafting. The further course was uneventful for this patient. Another patient revealed a wound complication in the initial postoperative follow-up, for whom a wound revision was performed 6 weeks after the index surgery. An otherwise uneventful postoperative course could then be observed in this patient. Another patient complained of persistent pain for 7 months at the site of the operated clavicle. However, the clinical and radiographic findings of this patient were normal and a computed tomography 5 months postoperative showed complete osseous healing and no signs of pseudarthrosis or screw loosening. Therefore, only intensive pain therapy was initiated for this patient. Otherwise, all of the patients showed a favorable postoperative course, were pain-free, and able to return to work, most within 5 weeks. After an average of 17 ± 8 months, 18 hardware removals (66.7%) were performed.

Our results are comparable to recently published studies [12–15]. In a systematic review and meta-analysis, Zhao et al. found no differences in terms of functional outcomes, operation time, and fracture healing comparing minimally invasive plate osteosynthesis and conventional open plating [12]. However, they reported

Zusammenfassung

Minimal-invasive Plattenosteosynthese von Klavikulafrakturen

Operationsziel: Behandlung von Trümmerfrakturen des Schlüsselbeins mit minimal-invasiver Plattenosteosynthese.
Indikationen: Multifragmentäre (≥ 2 intermediäre Fragmente) Klavikulaschaftfrakturen, die keiner anatomischen Reposition bedürfen (AO 15.2B & 15.2C). Auch einfache Frakturen (AO 15.2A) mit erheblichen Weichteilverletzungen (Tscherne Grad I–III) sind geeignet.
Kontraindikationen: Mediale oder laterale Klavikulafrakturen sowie einfache Frakturmuster, bei denen eine anatomische Reposition unerlässlich ist.
Operationstechnik: Kurze Inzision über dem medialen und lateralen Ende der Hauptfragmente. Epiperiostales Einbringen der Platte von medial oder lateral. Unter Bildwandlerkontrolle wird die Platte entweder superior oder anteroinferior auf der Klavikula zentriert platziert und mit einem Kompressionsdraht temporär (alternativ Kortikalisschraube) in einem der lateralsten Löcher fixiert. Reposition der Fraktur (Achse, Länge und Rotation) über die Platte und vorläufige Fixierung auch medial. Nach korrekter Reposition können weitere Kortikalisschrauben und/oder Kopfverriegelungsschrauben eingebracht werden („lag before lock"). Relative Stabilität wird durch eine Überbrückungstechnik erreicht.
Weiterbehandlung: Ruhigstellung ist nicht erforderlich. Die Patienten werden ermutigt, eine funktionelle Rehabilitation mit aktiver und passiver Physiotherapie durchzuführen. Die Belastung wird je nach dem radiologischen Verlauf sukzessive erhöht.
Ergebnisse: In einer retrospektiven Auswertung von 2001 bis 2021 wurden insgesamt 1128 Osteosynthesen des Schlüsselbeins durchgeführt, von denen 908 (80,5 %) mit einer Plattenosteosynthese und 220 (19,5 %) mit einem elastischen Titannagel (TEN) behandelt wurden. Von den 908 Plattenosteosynthesen wurden 43 (4,7 %) mit der minimal-invasiven Technik durchgeführt. Schlussendlich wurden 42 Patienten (35 Männer und 7 Frauen) mit einem Durchschnittsalter von 44 ± 15 Jahren mit 43 Klavikulaschaftfrakturen analysiert. Die Operation wurde in 63 ± 28 min durchgeführt, und die durchschnittliche Durchleuchtungszeit betrug 45 ± 42 s. Ein Kollektiv von 27 Patienten konnte nach einer medianen Follow-up-Zeit von 14 Monaten (Spanne 1 bis 51 Monate) ausgewertet werden. Es heilten 26 Frakturen zeitnah aus. Bei einem Patienten trat eine Pseudarthrose auf, die mit einer Re-Osteosynthese und Spongiosaplastik in offener Technik behandelt wurde. Bei einem weiteren Patienten trat eine Wundkomplikation auf, welche 6 Wochen nach der Indexoperation eine operative Wundrevision erforderlich machte. Der weitere postoperative Verlauf war bei beiden Patienten ereignislos. Alle Patienten waren schmerzfrei und konnten ihre Arbeit wieder aufnehmen. Es wurden 18 Metallentfernungen (69,2 %) nach durchschnittlich 17 ± 8 Monaten durchgeführt.

Schlüsselwörter
Funktionelle Ausrichtung · Strahlenbelastung · Geschlossene Reposition · Weichteilverletzungen · Multifragmentäre Frakturen

a benefit regarding skin numbness and complications. This was also confirmed by Ko et al. who observed significantly fewer injuries to the supraclavicular nerve while performing a minimally invasive technique [15].

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Declarations

Conflict of interest. C. Michelitsch, F. Beeres, M.D. Burkhard, P.F. Stillhard, R. Babst and C. Sommer declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies mentioned were in accordance with the ethical standards indicated in each case.

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