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TRAUMA SURGERY

Problems of bridging plate fixation for the treatment of forearm shaft fractures with the locking compression plate

Philipp Henle · Kevin Ortlieb · Kerstin Kuminack · Christof A. Mueller · Norbert P. Suedkamp

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Abstract
Introduction Treatment of diaphyseal forearm fractures by open reduction and internal plate fixation is a well-accepted strategy. In a variety of fracture localizations, the use of bridging plate fixation with locking compression plates (LCP) has been shown to improve biomechanical and biological characteristics. Only very limited clinical data are available on bridging plate fixation using LCPs for the treatment of diaphyseal forearm fractures. The aims of this study were to assess both clinical outcomes of LCP fracture treatments, and the implant-specific advantages and disadvantages.
Method The study consisted of 53 patients. All relevant data were extracted from the medical reports and radiographs. Of the 53 patients, 39 completed the disabilities of the arm, shoulder and hand (DASH) questionnaire and 35 patients were available for clinical examination. The mean time of follow-up was 23.3 months.
Results Thirty-nine fractures of the radius and 45 fractures of the ulna were treated with 3.5 mm LCPs. Due to a fracture non-union, four patients underwent a second operation. In 13 patients, hardware had already been removed at the time of follow-up. Complete documentation of the removal operation was available for ten patients; in seven of these, procedures difficulties occurred. Mean ranges of motion were 138°, 141° and 162° for elbow flexion–extension, wrist flexion–extension and pronation–supination, respectively. The mean DASH score was calculated at 14.9.
Conclusion In conclusion, our data show that clinical and functional outcomes of LCP plating of diaphyseal forearm fractures are comparable to the use of conventional implants. However, implant-specific problems during hardware removal must be considered.

Keywords Forearm · Radius · Ulna · Fracture · Bridging plate fixation · Locking compression plate · LCP · Fixateur interne

Introduction

Open reduction internal fixation using compression plates is a commonly accepted treatment of diaphyseal forearm fractures in adults [6]. With conventional implants, the achievement of interfragmentary compression is associated with a substantial degree of surface pressure on the bone surface and the periosteum beneath the plate. This mechanical stress on the periosteal layer might alter the vascularization of the fractured bone and thereby impede the healing process. Several alternative fixation techniques have been designed to address this problem, such as the limited contact dynamic compression plate (LC-DCP) and other internal fixators. The locking compression plate (LCP) combines features of an internal fixator with the dynamic compression concept. Each hole can be used with

P. Henle (✉) · K. Ortlieb · K. Kuminack · C. A. Mueller · N. P. Suedkamp
Department of Orthopaedics and Traumatology, University of Freiburg, Hugstetter Str. 55, 79106 Freiburg, Germany
e-mail: philipp.henle@insel.ch

P. Henle
Department of Orthopaedic Surgery, Inselspital, Bern University Hospital, and University of Bern, Bern, Switzerland

C. A. Mueller
Department of Orthpaedics and Traumatology, Staedtisches Klinikum Karlsruhe, Karlsruhe, Germany

a locking screw for fixed-angle stability or with a conventional screw in the gliding part to attain interfragmentary pressure. This combination is thought to offer both biomechanical and biological advantages. However, for the treatment of diaphyseal fractures of the forearm, so far there are only limited clinical data available to support this theory [10].

The main aims of this study were the clinical evaluation of LCP in the treatment of radial, ulnar or combined shaft fractures and the comparison to existing data on conventional implants.

Patients and methods

All patients with a diaphyseal fracture of the radius and/or ulna who, between October 2001 and October 2005, were treated operatively with LCP osteosynthesis at our institution were identified. A retrospective analysis was performed to collect information on patient demographics, cause and type of injury, and characteristics of the surgical interventions including complications that arose during surgery. The outcome was measured by use of a questionnaire and a standardized physical examination.

Inclusion and exclusion criteria

For inclusion in the study, the existence of at least one diaphyseal forearm fracture as defined by the AO/ASIF [11] was required. To reduce the influence on the data of treatment-independent variables, patients with additional severe injuries, pre-existing functional deficiencies on the respective extremity and pathological fractures, as well as adolescents with open growth plates, were excluded from the analysis.

Type of injury

Fractures were classified according to the AO/ASIF's comprehensive classification of fractures [11]. The associated soft tissue damage was assessed using the Gustilo and Anderson classification [4] for open fractures and the Tscherne and Oestern classification [13] for closed fractures. Severe concomitant injuries such as traumatic brain injury, spinal cord injury, fractures as well as blunt abdominal or thoracic trauma were also documented.

Surgical treatment

With regard to the operative treatment, the time point of the intervention, used implants, fixation technique (dynamic compression or internal fixator) and the duration of the operation were analyzed. If at the time of follow-up the hardware had already been removed, data from the operation and any ensuing complications were also noted.

The operative strategy was dependent on the fracture type. In double bone fractures, the simpler fracture was treated first for the control of length. If references for rotation were not available, the first fracture was only preliminarily stabilized. While reducing and stabilizing the second fracture, and in cases with only one fractured bone, forearm rotation was regularly controlled. A simple transverse fracture was fixed with dynamic compression by use of at least one gliding hole of the LCP. In a simple oblique fracture, first a lag screw was inserted to compress the main fragments followed by the LCP, which acted as an internal fixator to neutralize torsional forces. In a complex fracture pattern, the LCP was also used with locking screws in a bridging plate fashion. Plate length was chosen, wherever possible, to allow three screws to be placed in every main fragment.

Follow-up

All relevant radiographs were digitally archived and included in the study allowing us to track the process of fracture consolidation as well as possible hardware failures. For additional information, all available medical records were reviewed. Fracture consolidation was assumed when an uninterrupted bridging callus formed and/or if three of the four cortices on two plane radiographs were shown in continuity.

All identified patients were contacted and invited for a follow-up visit. The German version of the disabilities of the arm, shoulder and hand (DASH) questionnaire [3] was sent to each patient. If a patient was not able to attend a physical examination, data from the questionnaire were obtained if possible and included in the analysis.

The standardized examination protocol, which consisted of a range of motion testing on elbow and wrist as well as an assessment of neurological deficits, was performed by a single investigator (KO).

Results

Patient demographics

A total of 53 patients were selected on the basis of the study protocol and included in the analysis. Documentation until fracture consolidation was available for 43 (81%) patients. DASH scores could be obtained from 39 (74%) patients, and 35 (66%) patients were available for a physical examination. The most common reason for a loss of follow-up was outdated contact information ($n = 11$).

Two patients refused a physical examination for personal reasons, one was deceased (cause of death unrelated to study injury), and four lived too far away to attend a follow-up examination at our clinic, but completed the questionnaire. The study group consisted of 45 males and 8 females. The mean age at the time of injury was 35.9 years (15–72 years). The medium time of follow-up was 23.3 months.

Type of injury

Of the 53 patients included in this study, 31 (58.5%) had sustained a both bone fracture of the forearm, 8 (15.1%) had a *Galeazzi* lesion and 14 (26.4%) a *Monteggia* lesion. Therefore, a total of 39 radius fractures and 45 ulna fractures could be analyzed (AO/ASIF classification of the fractures is summarized in Table 1). The most common fracture type was a combined simple fracture of the radius and ulna (22-A3). The majority of fractures was associated with none or only insignificant soft tissue damage (Tscherne 0, $n = 29$). A detailed overview on associated soft tissue injuries is presented in Table 2. Sixteen patients had open fractures. Motor vehicle accidents were identified as the predominant cause of injury ($n = 16$). All traffic accidents, which are commonly rated as high-energy trauma, accounted for 58.5% ($n = 31$) of all sustained fractures (Table 3). A total of 25 patients sustained monotrauma forearm fractures and 28 had concomitant injuries (Table 4).

Table 1 Type of fractures according to the AO/ASIF classification

	22.A.×	22.B.×	22.C.×
22.×.1	9	2	6
22.×.2	3	3	3
22.×.3	12	8	7
$\sum = 53$	24	13	16

Table 2 Fracture-associated soft tissue damage according to the classifications by Tscherne and Oestern (closed fractures), and Gustilo and Anderson (open fractures)

Grade	Closed fractures (Tscherne and Oestern)	Open fractures (Gustilo and Anderson)
0	29	–
1	4	12
2	3	2
3	1	2
$\sum = 53$	37	16

Table 3 Cause of injury

Accident	*n*
Motor vehicle	16
Motorcycle	9
Sports	9
Bicycle	6
Leisure activity	5
Work	4
Violence	3
Unknown	1
	53

Table 4 Concomitant injuries: multiple entries are possible

Injury	*n*
Fracture(s) at lower extremity	17
Traumatic brain injury	13
Blunt thoracic trauma	10
Vertebral fractures (w/spinal cord injury)	6 (1)
Pelvic fractures	5
Blunt abdominal trauma	3
Contralateral fracture at the upper extremity	2

Table 5 Implanted device sizes

Holes (mm)	5 (72)	6 (85)	7 (98)	8 (111)	9 (124)	10 (137)	11 (150)
Radius	3	9	21	6	4	1	1
Ulna	1	7	26	4	–	–	1
$\sum = 84$	4	16	47	10	4	1	2

All implants are 3.5 mm titanium LCP (Synthes Europe, Solothurn, Switzerland)

Surgical treatment

In 67.9% (36 patients) of the cases, surgery was carried out within 24 h after trauma. Another 13.2% (7 patients) were operated on the day after the injury. In all cases, at least one 3.5 mm (small fragment) titanium LCP (Synthes Europe GmbH, Solothurn, Switzerland) was used for fracture stabilization (3.5 mm LCPs vary in size between 4 and 12 holes, 59–163 mm). However, in our study, only plate sizes ranging from 5 to 11 holes (72–150 mm) were used (Table 5). The seven-hole LCP was used in 50% of all fractures. Seven fractures were treated using the dynamic compression technique, meaning that a combination of locking and gliding screws was used. As much as 77 fractures were treated by the principle of the internal fixator with a bridging plate and locking screws only. Operations were performed by 26 different surgeons. The overall mean operating time was 115 min (31–445 min). The mean operating time for double

Table 6 Operating time (min)

Fracture/time	<40	40–59	60–79	80–99	100–119	120–139	140–159	160–179	≥180
Combined		3	2	4	6	3	4	4	5
Radius		2	3	1	1	1			
Ulna	1	7	3	1		1		1	
$\sum = 53$	1	12	8	6	7	5	4	5	5*

* All patients with operating times >3 h had at least one additional intervention besides the forearm fixation

Table 7 Patients with non-unions: demographics

Sex	Age	Fracture type	Open/closed	Concomitant injuries	Time until revision (weeks)
m	53	22 B1.3	Closed	TBI, Pipkin IV fracture	14/22
m	18	22 C2.3	Open	Contralateral ulna fracture	30
m	40	22 B3.1	Closed	TBI, open femur and tibia fractures	14
m	72	22 B3.2	Closed	Bilateral femur fractures, thoracic trauma, stable vertebral fracture	n/a

TBI traumatic brain injury, *n/a* not available

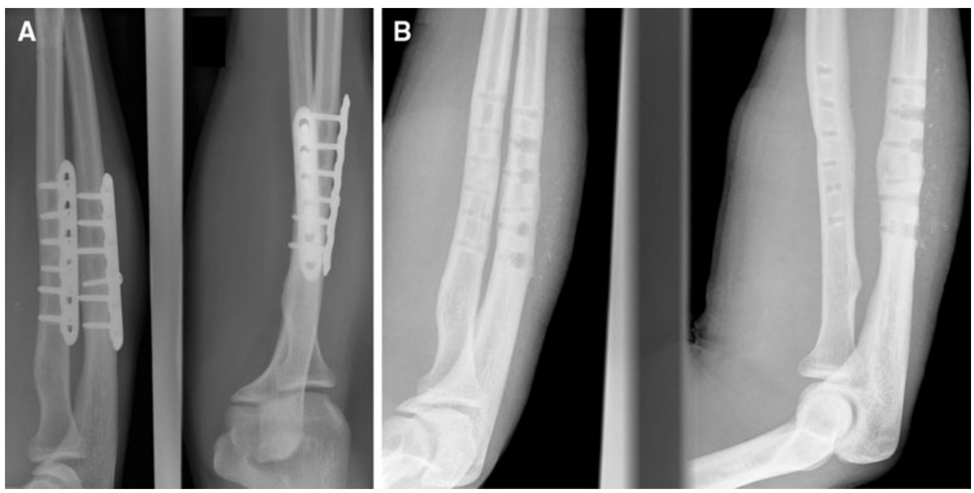

Fig. 1 Case example 1. This 17-year-old male patient with an AO 22 A 3.2 fracture was treated with two LCPs in dynamic compression technique where one screw was placed into the gliding hole. Hardware removal of the ulnar plate was possible without complications. At the radius, all five locking screws were cold welded to the plate. Screw heads had to be drilled out of the plate and the remaining screw fragments had to be rescued by the use of a hollow drill, leaving large bone defects and metal debris within the surrounding soft tissue

bone fractures was 145 min (51–445 min), and 78 min (48–133 min) and 83 min (31–165 min) for isolated radius and ulna fractures, respectively (Table 6). All patients with operating times of more than 3 h had at least one additional intervention besides forearm fixation.

Fracture union, complications, hardware removal

In 35 (a total of 70 fractured bones) of the 43 patients, radiographic fracture consolidation was achieved within 16 months following the index operation. Two fractures healed after this period without further intervention. Additional surgery for the treatment of complications with regard to the osteosynthetic procedure was necessary in seven cases, four of which (5.7% of the fractured bones) had to undergo a second stabilization operation due to non-union of the fracture (Table 7). In one of these cases, a third operation was necessary for the achievement of fracture union. One patient developed a superficial wound infection that was treated successfully by operative revision and intravenous antibiotics. Two plates had to be replaced: one due to a refracture of the ulna within the stabilized portion of the bone and one due to loosening of the implant.

Thirteen patients had their hardware removed during the follow-up period. Ten operations were performed at our institute and complete documentation was available from the other treating hospitals. The mean duration from the initial surgery until removal of the plate(s) was 21.8 months (12–34 months). Of the ten cases with complete documentation on the removal operations, complications arose in seven. Six patients had at least one screw cold welded to the plate; attempts at unscrewing resulted in a damaged screw head. Two of these screws could be recovered by use of the specific extraction device for damaged screw heads. In four cases, trephine drilling was necessary for retrieval of the implant parts (Fig. 1). During

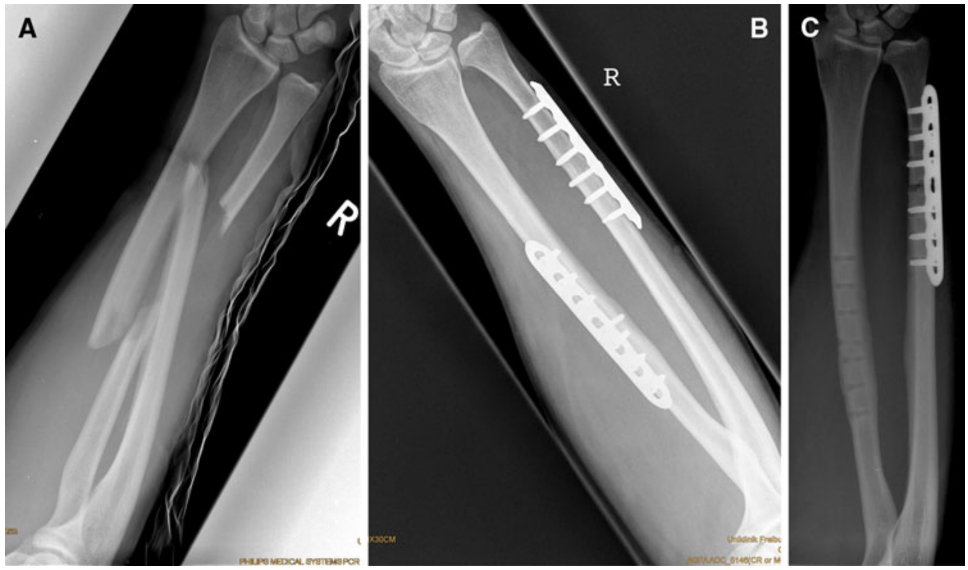

Fig. 2 Case example 2. A 24-year-old male patient who sustained an AO-type 22 A 3.2, Gustilo type I open fracture in a motor vehicle accident (**a**). Open reduction and internal fixation was performed with LCPs in the fixateur interne technique. Hardware removal was scheduled 23 months after the initial surgery at the well-consolidated fracture sites (**b**). Two screws of the ulnar LCP were cold welded to the plate. In an attempt to rescue the screw fragment after drilling off the screw head, a fracture occurred at the screw hole necessitating re-stabilization (**c**)

Table 8 Functional outcome I: range of motion, mean (minimum–maximum)

Elbow: extension/flexion	1° (0–10°)	137° (125–150°)
Wrist: extension/flexion	69° (30–90°)	72° (45–90°)
Pronation/supination	77° (30–90°)	86° (55–110°)

Table 9 Functional outcome II: DASH scores

Type of fracture/ DASH score	0	1–10	11–20	21–30	31–40	41–50	>50
Type A, $n = 18$	5	8	4	1			
Type B, $n = 11$		5	1	4	1		
Type C, $n = 10$	2	2	2	1		2	1
Total, $n = 39$	7	15	7	6	1	2	1

this process, one refracture of the ulna occurred (Fig. 2) and one broken screw was advertently left in situ. The mean operating time for the removal operations was 117 min (67–224 min).

A radio-ulnar synostis was not observed in any of the cases included in this study.

Functional outcome

Physical examinations showed mean ranges of motion of 138° (125–155°), 141° (100–170°) and 162° (90–200°) for elbow flexion–extension, wrist flexion–extension and pronation–supination, respectively (Table 8). The mean DASH score for all the patients was 14.9 (0–85, Table 9). The severity of the fracture correlated with higher mean DASH scores (Type A: 7.9; Type B: 23.8; Type C: 25.9). Patients with previously removed hardware had a mean DASH score of 8.8. In the four patients with non-union fractures, the mean DASH score increased to 28.1.

Seven patients (13%) complained of paresthetic sensations in the affected forearm or hand. One patient had a complete loss of sensation around the ulnar nerve.

Discussion

To our knowledge, only one other research study on the use of locking compression plates in the treatment of diaphyseal forearm fractures has been recently published [10]. No clear scientific evidence favors or rejects implants for fracture localization or even for more specific types of fractures. Therefore, more detailed clinical data are needed to determine the benefit of LCPs in the treatment of forearm shaft fractures [8].

Other implants suitable for this fracture localization are the dynamic compression plate (DCP) and the limited contact dynamic compression plate (LC-DCP), both of which are still widely used in the treatment of forearm fractures. In 1996, Hertel et al. [6] studied 132 cases treated with DCPs. In this study group, they had two non-unions (1.5%), one infection (0.76%) and one radio-ulnar synostosis (0.76%). No statements were made on hardware removal and associated problems or on clinical outcome measures. Data on LC-DCPs by Leung and Chow are somewhat more recent [9]. In their study, data are provided for 47 patients (56 fractures). They reported no non-unions but, in contrast to our definition, five fractures (8.9%) that united after more than 24 weeks were still rated as delayed unions. In comparison to these analyses, in our study group treatment with LCPs did not result in superior fracture unions.

The clinical outcomes were not easily comparable because DASH scores were not available for the studies by Hertel et al. [7] and Leung and Chow. However, the mean DASH score of 14.9 of our study group was well within the range of the normal population with 13 ± 15 (mean ± standard deviation). Of the four patients with a DASH score of 30 or higher, three had undergone revision surgery for treatment of a non-union. This highlights the character of non-union as a predictor for poor clinical outcome.

In the study by Leung and Chow, full range of motion was considered to be a less than 10% loss of wrist extension–flexion and less than 25% loss of pronation–supination [9]. With the LC-DCP implant, full range of motion was attained in 98% of the patients. Applying the same definition to our study group, 97% of the patients had full range of motion at the time of follow-up.

Leung and Chow also published the single existing report on LCPs for the treatment of forearm fractures [10]. In this study of 32 patients, there were no non-unions, two delayed unions (6.3%) and two implant failures (6.3%). In addition, two refractures (6.3%) occurred after implant removal. Their clinical outcome, in terms of range of motion, was 74% full and 26% slightly affected range of motion. They concluded that in the treatment of forearm fractures, the use of LC-DCP implants was not found to be significantly better than conventional implants.

In theory, the fixed connection between plate and screws in LCP implants adds stability to the osteosynthesis. Under specific conditions, such as osteoporotic bone or severely comminuted fractures, this added stability might offer clinical advantages [1]. However, from the presented data it seems unlikely that this holds true in the case of diaphyseal forearm fractures. Our clinical findings are supported by a cadaver study of radius fractures, where biomechanical properties of LCPs have been shown to be very similar to those of LC-DCPs [2].

When using locking plates, a specific concern needs to be taken into consideration. As our analysis of hardware removal shows, the majority of these operations are associated with difficulties related to the locking mechanism. To reduce the chance of a problem arising, we strongly recommend manually inserting all locking screws. Manual insertion will avoid cold welding. Hardware removal should only be performed with clear clinical indication and, to avoid refractures, never within the first 18 months following fixation [10].

In addition, because of the entirely different biomechanical concept, specific preoperative planning is mandatory when using LCPs. In contrast to conventional implants, the trajectory of the screws is defined by the plate, thereby limiting the surgeon's choice in screw placement. Bending of the plate for anatomic precontouring is strongly discouraged because it might damage the locking mechanism and it does not increase stability in these kinds of implants [5]. Furthermore, rigidity of the plate varies with the number and placement of screws and, therefore, the LCP should be adjusted to the type of fracture [12].

As shown, the LCP concept is associated with specific advantages and disadvantages. Under several circumstances, such as in osteoporotic bone, a severely comminuted fracture or a distinct fracture localization, the advantages of LCP might outweigh the disadvantages. With regard to diaphyseal forearm fractures, no clear benefits were found in terms of fracture union or outcome when comparing our LCP data with those available for DCP and LC-DCP control groups. Knowing this, great consideration must be taken when deciding on which form of implant, LCP or DCP/LC-DCP, would be in the patient's best interest. Moreover, more data are needed to identify fracture types or possible circumstances under which LCP plating should be recommended.

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References

1. Egol KA, Kubiak EN, Fulkerson E, Kummer FJ, Koval KJ (2004) Biomechanics of locked plates and screws. J Orthop Trauma 18:488–493
2. Gardner MJ, Brophy RH, Campbell D, Mahajan A, Wright TM, Helfet DL et al (2005) The mechanical behavior of locking compression plates compared with dynamic compression plates in a cadaver radius model. J Orthop Trauma 19:597–603
3. Germann G, Wind G, Harth A (1999) The DASH (Disability of Arm–Shoulder–Hand) Questionnaire—a new instrument for evaluating upper extremity treatment outcome. Handchir Mikrochir Plast Chir 31:149–152
4. Gustilo RB, Anderson JT (1976) Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 58:453–458
5. Haug RH, Street CC, Goltz M (2002) Does plate adaptation affect stability? A biomechanical comparison of locking and non-locking plates. J Oral Maxillofac Surg 60:1319–1326
6. Hertel R, Pisan M, Lambert S, Ballmer FT (1996) Plate osteosynthesis of diaphyseal fractures of the radius and ulna. Injury 27:545–548
7. Jester A, Harth A, Germann G (2005) Measuring levels of upper-extremity disability in employed adults using the DASH Questionnaire. J Hand Surg (Am) 30:1074
8. Larson AN, Rizzo M (2007) Locking plate technology and its applications in upper extremity fracture care. Hand Clin 23:269–78, vii
9. Leung F, Chow SP (2003) A prospective, randomized trial comparing the limited contact dynamic compression plate with the point contact fixator for forearm fractures. J Bone Joint Surg Am 85-A:2343–2348
10. Leung F, Chow SP (2006) Locking compression plate in the treatment of forearm fractures: a prospective study. J Orthop Surg (Hong Kong) 14:291–294

11. Mueller ME, Nazarian S, Koch P, Schatzker J (1990) The comprehensive classification of fractures of long bones. Springer, Berlin, Heidelberg, New York
12. Stoffel K, Booth G, Rohrl SM, Kuster M (2007) A comparison of conventional versus locking plates in intraarticular calcaneus fractures: a biomechanical study in human cadavers. Clin Biomech (Bristol, Avon) 22:100–105
13. Tscherne H, Oestern HJ (1982) A new classification of soft-tissue damage in open and closed fractures (author's transl). Unfallheilkunde 85:111–115