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PŮVODNÍ PRÁCE

Orthogonal Double Plate Fixation for Long Bone Fracture Nonunion

Ošetření pakloubu dlouhých kostí dvěma na sebe kolmo fixovanými dlahami

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ABSTRACT

PURPOSE OF THE STUDY

The treatment of long bone diaphyseal fracture-nonunion is challenging. While taking into account biological needs, a stable mechanical environment is pertinent for fracture healing. This work aims at evaluating the surgical management of stubborn ununited fractures using orthogonal double plating of diaphyseal fractures with limited periosteal stripping and soft tissue dissection.

PATIENTS AND METHODS

Retrospective analysis in a level I trauma center. Between the years 2007–2009, 22 patients were treated with double plating due to nonunion of long bone fractures. Long bones included three clavicles, six humeri, three femora, seven ulnae, two tibiae and one radius. The mean period between index procedures (if existed) and revision procedures was 53.35 weeks (range 6 months-3 years). The same surgical technique, independent on the anatomical location was utilized. Perioperative intravenous antibiotics were withheld until intraoperative cultures were obtained in all patients. An approach to the fracture site was performed with removal of all previous existing hardware, including aggressive debridement of the nonunion site while keeping stripping to the necessary minimum. After primary plate fixation of the fracture with adequate compression, a second plate, with at least two well spaced screws on each side, was placed at a ninety degree angle to the primary plate. Autologous bone graft or bone graft substitute was placed in most, but not all cases. All procedures and assessment of union were done by fellowship trained trauma surgeons. In the infected cases, culture specific intravenous antibiotics were administered for six weeks. Quality of life measures included DASH score of the upper extremity, lower extremity functional score (LEFS) for the lower extremity and Short From 12 (SF-12) for all patients.

RESULTS

Union was achieved in all patients, with an average time to union of 5.8 months (range 2–24 months). One patient healed after a repeat double plating, since the first procedure was unsuccessful. Tissue culture were positive in 11 out of 22 patients. One clavicular plate was removed, due to irritation. No hardware failure was noted in these cases. Mean LEFS was 59%, quick DASH score –18.5 20 and SF-12 MCS and PCS were 50.37 15.22 and 49.96 8.5 receptively.

CONCLUSION

Double plating is a biomechanically sound option for treating long bone fracture nonunion with reasonable results, provided adequate biological conditions are met including eradication of infection.

Key words: plate fixation, long bone nonunion, double plate technique.

INTRODUCTION

Nonunion of long bone fractures is a major therapeutic challenge for trauma surgeons, being a debilitating unacceptable condition (19). Advances in fracture care and modern implant designs have lead to a marked reduction of the diaphyseal nonunion rate over the past decades (10, 13, 26, 32).

The sucessful treatment of nonunions requires the utilization of numerous resources (4), especially when infection is concerned. The desired primary treatment outcome of a long bone nonunion is restoration of a functional, painless, well-aligned, infection-free limb. Meticulous soft tissue handling and preservation of the periosteal blood supply in conjunction with rigid fixation are thought to increase union rates and minimize complications (5, 6).

Unlike acute, lower-extremity long bone fracture cases, when intramedullary fixation can be extremely successful (30), the use of extramedullary (plate) fixation for nonunions can be advantageous. The potential benefits of plating include adequate exposure of the fracture site allowing thorough debridement of fibrous tissue, a better control over limb alignment and axis, and direct application implants creating rigid fixation and interfragmentary compression. Thus, adequate direct bony contact under stable conditions can be obtained. Furthermore, newer studies have reported lower healing rates for intramedullary fixation of non-unions than previously expected (29). However, even with plate fixation, failures can occur.

Theoretically, the use of orthogonal double plating can provide a much stiffer construct than a single plate especially in resistance to torsion (24). Unlike parallel plating, the orthogonal position of the plates and the use of a smaller secondary plate can reduce the amount of soft-tissue stripping and de-vascularization of the bone while maintaining the mechanical advantage of double plating.

The aim of this study was to report our results and patient outcome following a single stage therapeutic protocol consisting of orthogonal double plating in a variety of long bone non-unions including the humerus, forearm, femur, proximal tibia and clavicle.

PATIENTS AND METHODS

Study design: retrospective cohort study. Between 2005 to 2009, 22 consecutive cases of long bone fracture nonunion treated with double plating were performed in an academic, level-I trauma center. Inclusion criteria included a diagnosis of an established nonunion of a long bone shaft, treatment with definitive internal fixation using orthogonal double plating, and adequate radiographic and clinical follow-up of a one year minimum. Nonunion was defined as an unstable fracture with a lack of progressive healing following three consecutive radiographs, or the persistence of an obvious non-united fracture a minimum of six months from initial injury or surgery (17, 18). Non-union of bones was classified according to criteria of Weber and Cech (28); and included five oligotrophic nonunions while the remainder were atrophic nonunions.

The study group consisted of 16 male and six female patients, with an average age of 40.82 years (range 13–81 years).

Injury mechanisms included 13 falls, six motor vehicle collisions, one gunshot, crush injury and one iatrogenic fracture following limb lengthening procedure of the femur. One of the injuries was initially an open fracture. Two patients were smokers. Four patients had multiple medical co-morbidities, including non-insulin dependent diabetes, and HCV cirrhosis. The mean time from index procedure/initial fracture to revision surgery was 11 months. The number of index procedures performed prior to the double plating one included sixteen open reductions and internal fixations with plate and screw constructs for fractured clavicle, humerus, ulna, radius, femur, tibia; one tension band for proximal ulna fracture, one intramedullary femoral nail, and two closed reduction of humerus. Two humerus and one clavicle fractures were treated initially non-operatively.

Bone gap indicating either inadequate compression or segmental bone loss at the index surgery was observed in six patients, with mechanical failure occurring altogether in 9 cases (Table 1).

TREATMENT PROTOCOL

Prior to surgery, in all cases known to be infected, antibiotic treatment was halted at least ten days prior to the surgical procedures in order to increase the yield of intraoperative cultures. In all cases, regardless of documented infection or not, prophylactic intravenous antibiotic was withheld until at least four intraoperative tissue cultures were obtained. Antibiotic treatment was initiated intraoperatively after obtaining cultures, based on previous cultured microorganism if any; otherwise first generation intravenous cephalosporin prophylaxis (*cefazolin i. v. 1 g tid*) was initiated. Previous incisions were utilized whenever possible. All existing hardware, if present, was removed. A thorough debridement of the fracture site, until bony surfaces were exposed and nonunion and fibrous tissues were sharply resected. Sinus tracts were sharply excised. The fracture ends were mobilized enough for reduction purposes but care was taken to avoid excessive stripping. Bone was spared as much as possible and bone resection was avoided or was minimal. The medullary canal was drilled. Open reduction and internal fixation with correction of deformity, if existed and alignment in both the coronal and sagittal planes were performed next. Fixation was undertaken using a primary plate on the tensile side of the bone. An additional, usually smaller plate was then placed in orthogonal position to the primary plate. Plate types are specified in Table 1. Bone graft, either as autologous iliac crest cancel-

Table 1.
DCP – Dynamic Compression Plate, LCP – Locking compression plate, recon – reconstruction plate, PHLP – proximal humerus locking plate (PHILOS). All implants are made by Synthes (Soluthern, Switzerland)
ICBG – iliac crest bone graft
DBM – Deminerlized Bone Matrix

Case number	Gender	Age	Mechanism	Fracture site	AO/OTA	Nonunion type	Past medical history	Previous implant	Revision implants	Complication at presentation	Augmneta-tion	Compli-ca-tions	cultu-res	Antibiotic treatment	Months to union
1	F	76	Fall	Femur	32A2	Atrophic	Osteoporosis	IMN (twice),	4.5 LCP + 3.5 recon	None	None	-	-		4 (2nd proc)
2	F	26	MVA	Femur	32C2	Atrophic	-	LCP- DHS	4.5 LCP + 3.5 recon	Wound infection	ICBG	-	+	Ampicillin & Gen-tamicin	9
3	M	13	Iatrogenic	Femur	32A2	Oligotrophic	-	LCP	4.5 LCP + 3.5 recon	wound infection	None	-	+	cefazolin	6
4	F	42	Fall	Humerus	13A1	Atrophic	-	T-plate	3.5 LCP + 3.5 recon	Radial nerve palsy	DBM	-	+	Rifampicin & Ofloxacin	2
5	F	73	Fall	Humerus	12A1	Oligotrophic	COPD, HTN, Smoker	LCP	3.5 PHLP + 3.5 LCP	None	ICBG	-	-		4
6	M	19	Traumatic ampuation	Humerus	12C3	Oligotrophic	-	PHILOS	3.5 PHLP + 3.5 LCP	Amputation at presenta-tion	DBM	-	+	Ceftazidime & Amikacin	24
7	M	60	Fall	Humerus	12A1	Atrophic	Dyslipidemia	Non-op	3.5 LCP + 3.5 LCP	None	DBM	-	-		2
8	M	29	Fall	Humerus	12B3	Oligotrophic	-	EX-FIX	4.5 LCP + 3.5 LCP	Wound infection	DBM	-	-		6
9	M	60	mva – multi-ple trauma	Humerus	12B1	Atrophic	-	Non-op	3.5 PHLP + 3.5 LCP	None	ICBG	Radial injury	-		6
10	M	78	Fall	Ulna	21A3	Atrophic	DM, HTN	Tension band wiring	3.5 LCP + 3.5 recon	Motor ulnar palsy	ICBG	-	-		6
11	M	28	gun shot	Ulna	21C3	Atrophic	-	Plate	3.5 LCP + 3.5 recon	Motor ulnar palsy	ICBG	-	-		6
12	M	36	Fall	Ulna	22C1	Atrophic	-	Plate		Motor ulnar palsy	ICBG	-	+	Sulphametoxazole Trimethoprim	5
13	F	75	Fall	Ulna	22A1	Atrophic	HTN, DM	Plate	3.5 LCP + 3.5 recon	Wound infection	DBM	-	+	Cefazolin	N/A
14	M	28	MVA	Ulna	22B1	Atrophic	HCV, Drug abuse, Smo-king	Plate	2.7 DCP + 2.7	None	None	Ulnar injury	-		2
15	M	25	MVA	Ulna	21B1	Atrophic	-	plate		None	None	-	+		6
16	M	41	fall- open	Ulna	21C3 OG2	Atrophic	-	Plate		None	None	-	-		4
17	M	27	Fall	Radius	22C1	Atrophic	-	Plate	3.5 LCP + 1/3rd tubular	Skin necrosis	None	DRUJ insta-bility + skin secrosis	+	Sulphametoxazole Trimethoprim & Ciprofloxacin	3
18	M	27	Fall	Clavicle	15A3	Atrophic	-	Non-op	3.5 LCP + 2.4 LCP	None	ICBG	-	+	Cefazolin	7
19	M	32	Fall	Clavicle	15A2	Atrophic	-	Plate	2.7 DCP + 2.7 recon	None	ICBG	-	+	Cefazolin	4
20	M	57	Fall-Bicycle	Clavicle	15A2	Atrophic	-	Plate	3.5 LCP +2.7 1/3rd tubular	None	None	-	-		5
21	M	31	mva	Tibia	42C3	Atrophic	-	LCP	4.5 LCP + 3.5 LCP	None	ICBG	-	-		7
22	F	81	mva – multi-ple trauma	Tibia	41A1	Oligotrophic	-	LCP	4.5 LCP + 3.5 DCP	none	ICBG		+	vancomycin	5

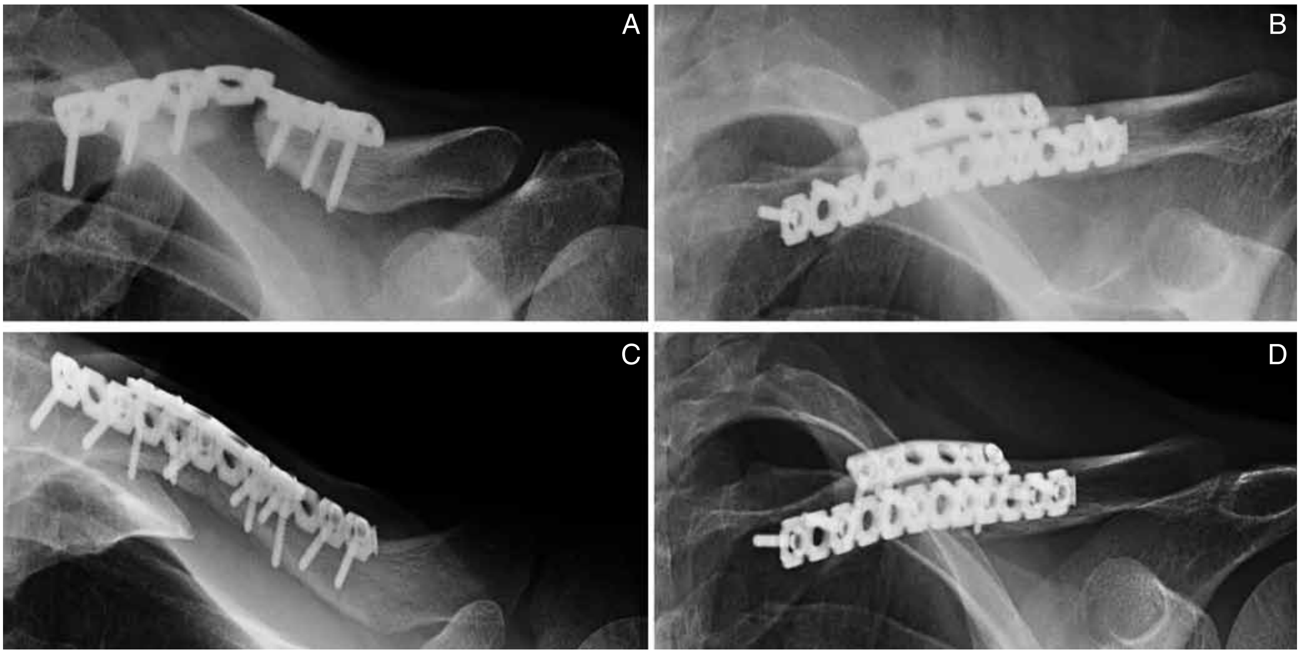

Fig. 1. Radiographs of a 32-year-old male who was injured in a motorcycle accident and was operated twice for his clavicle fracture elsewhere and presented with a nonunion (A). All hardware were removed and the fracture was fixed with a long 2.7 reconstruction plate and a 2.7 mm DCP plate with iliac crest bone grafting (B). Intraoperative cultures were positive for Propionibacterium acnes and the patient was treated for six weeks with intravenous antibiotics. At one year (C and D) postoperatively the patient is totally asymptomatic and is back to full activity including surfing.

lous bone or demineralized bone matrix (Allomatrix, Wright Medical Technology, Arlington TN) was applied to the nonunion site in most cases in the absence of gross infection. Postoperative care was tailored to the treated bone, with restricted weight bearing for six weeks for the lower extremity and initiation of active and active assisted range of motion in two-weeks postoperatively for upper extremity nonunions. All patients received intravenous antibiotics pending the results of intraoperative cultures. In cases of positive intraoperative cultures, organism specific intravenous antibiotics were administered under the direction of the infectious disease service for six weeks.

All patients were followed in the outpatient clinic at two weeks, six weeks, three months, six months and one year postoperatively.

Radiographic evaluation: Fracture healing was defined as painless weight bearing (lower extremity) and bridging of 3 out of 4 cortices, assessed by a fellowship trained orthopedic trauma surgeon, blinded to the patients' results. Shortening was assessed by measuring the differences in length of the operated bone using a CAD software (TraumaCAD, Voyant Health Israel), after calibrating the image for known screw diameters.

Evaluation: Patients with upper limb fractures rated the functional outcome by using the shortened Disabilities of the Arm, Shoulder and Hand (Quick-DASH) questionnaire. Lower limb patient group rated their functional outcome according to the Lower Extremity Functional Scale (LEFS) (3). General health survey score was evaluated using the short form (SF-12) questionnaire (1).

RESULTS

Results are summarized in Table 1. Long bones included: three clavicles, six humeri, three femora, five ulnae, two proximal tibia and one radius shaft. Time to union averaged 7 months (range 2–39 months).

Altogether, 11 cases out of 22 were infected according to intraoperative cultures results. Infective agents were *Staphylococcus species coagulase negative* in four cases, *Propionibacterium acnes* in two cases, *Pseudomonas aeruginosa* in one case, *Enterobacter cloacae* in one case, *Enterobacter faecalis* in one case. Two cases had polymicrobial growths. In five cases which were clinically suspicious for infection, biopsies of tissues were sent to pathology. In those cases, regenerative changes, fibrosis, necrotic bone and chronic inflammation were observed.

All patients healed except for one patient who underwent another procedure of double plating and iliac crest bone grafting and healed 4 months subsequently. Average time for union was 5.8 months (range 2–24).

Complications included: Local irritation necessitating removal of implants form one clavicle, transient sensory ulnar nerve palsy, one case of ulna fracture resolved at three months postoperatively; and one case of transient radial palsy in humeral shaft fracture that completely resolved at four months.

One case of an infected forearm nonunion required skin grafting and had a sensory radial deficit. Also, due to postoperative distal radio-ulnar joint (DRUJ) instability required a Sauve-Kapandji procedure.

The average amount of shortening required to attain compression of the fractured ends following debride-

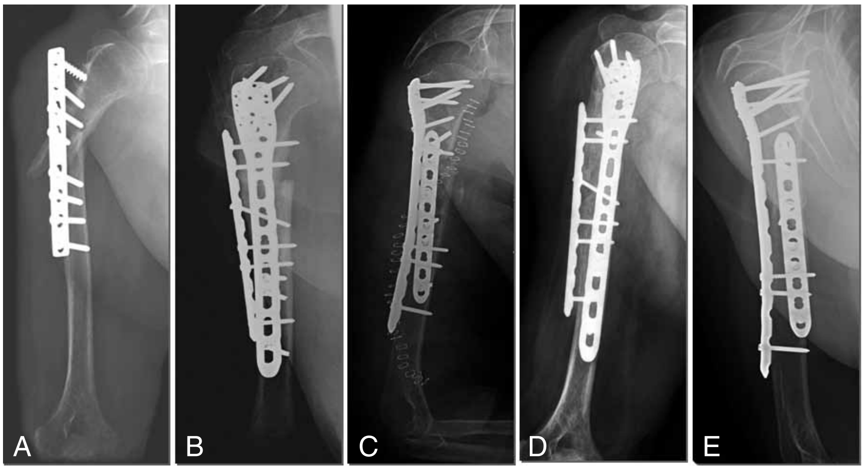

Fig. 2. Radiographs of a 73-year-old woman suffering from non-union following open reduction and internal fixation of a proximal humerus shaft fracture (A). Following removal of hardware and debridement, double plate construct of proximal humerus locking plate and an additional 3.5 mm locking plate was applied (B & C). At 6 months follow-up solid union and normal function were seen (D and E). Intraoperative cultures were negative for infection.

Fig. 3. Radiographs (A and B) of a 13-year-old girl who suffered a fractured femur following elongation procedure after osteomyelitis in childhood. Prior fixation with a 4.5 mm LCP had failed. Patient was taken into the OR and after removal of hardware a repeat fixation with 4.5 mm locking plate with an additional 3.5 mm reconstruction plate (B and C). Intraoperative cultures were positive for Staphylococcus aureues and intravenous cefazolin and rifampin therapy was administered for 6 weeks. At nine months following surgery (D and E) fracture healed and the patient returned to full function and remains asymptomatic.

ment was 3.34 2.34 mm (range 0–22 mm). However, no attempt was made to span a defect with graft, and instead great effort was made to ensure compression across the fracture site.

At time of evaluation the mean Quick-DASH score for upper limb function outcome was 18.5 (range, 0–64), with 0 the best and 100 the worst score. The mean LEFS was 59% with 100% the best and 0 the worst, SF-12 MCS and PCS was 50.37 15.22 and 49.96 8.5 receptively.

DISCUSSION

This study demonstrated an outcome of successful open reduction and internal fixation with orthogonal double plate constructs of nonunion long bones diaphyses. Although we dealt with revision surgery in mainly atrophic and infected patients, revision surgery complications were low. Functional outcome scoring for site specific, LFES and Quick DASH were acceptable, albeit not ideal. However, the general health survey (SF12) for both physical and mental scoring was within the healthy population norm. Also, limb shortening was minimal.

Several studies have highlighted the importance of double plate fixation technique especially in primary comminuted intra-articular fractures such as distal humerus. (16, 22, 23), and proximal ulna (20). Additionally, several mechanical studies of comminuted fracture of both humerus shaft distal humerus emphasized the superiority of double plate fixation in providing more stable fixation than any other constructs (8, 24). This concept is even more relevant in revision cases and non-unions, since in these, bone healing is slower and more compromised. Thus, the maintenance of a stable mechanical environment is necessary.

Given that concept, as rigidity is desired in many nonunion cases to allow the slow biological process to “kick in" prior to hardware failure, we adopted this concept in the hope of providing a favorable environment for fracture healing, since mechanical stability is known to be beneficial for the eradication of bone infection (7, 31); In our series, all but one case healed with no mechanical failures. In this one case, the initial fixation was done with a secondary non-rigid (3.5 reconstruction) plate for the femur and healed by applying a second stiffer plate. Still, additional evidence to support our assumption is needed.

Some additional evidence for the advantages of double plating, especially in humerus nonunion was previously reported by Rubel et al. (21), however, double plating was not the sole method of fixation involved in this series, so no direct conclusions of its superiority over a single plate could be drawn.

Our treatment protocol was single stage in all the cases since none of them were macroscopically and grossly infected, and all infections were subclinical and detected in intraoperative cultures only. Despite our results, a single stage protocol of treating grossly infected, purulent bone should be seriously considered before applied. In these cases, a multiple stage procedure might be more advisable.

Despite the use of multiple plates, we tried to minimize stripping and preserve blood supply as much as possible. Although applied in compression mode across the fracture site, the use of locking plates, when applied correctly, can minimize periosteal blood supply damage (27). Our results implicate the important role of locked plates in the treatment of nonunion. Besides providing a stiffer construct than non-locking plates, locking plates can, can provide more resistance against infection in experimental models (11, 14). Also, stable fixation can be achieved with locking plates in cases of unicortical bone loss (11, 14).

There are some unique features in our protocol related to specific bones. As clavicular non union has been widely investigated in the literature utilizing various implant types (9, 12, 15, 25), no previous descriptions of single staged internal fixation of low grade infected clavicle non union have ever been described. In our series, two infected cases of clavicle nonunions were successfully treated.

As for forearm infected non-unions, Barbieri and colleagues reported their experience in a case series of 12 patients treated by iliac crest bone block grafting and compression plating and reported a recurrent infection rate as high as 30% (2). Recently, an additional, staged protocol of treating infected forearm nonunion was described (18). In our series, all forearm nonunion, mostly infected, were successfully healed following our single stage protocol.

Our study has several shortcomings: the small number of subjects with various types of fractures and sites, variety of implants used and the retrospective nature of the study. However, given the not so common epidemiology of long bone nonunion and the use of alternative fixation options in many cases (especially in the lower limb where intramedullary nailing prevail), a much larger series would be hard to obtain from a single center.

As long bone nonunion, especially infected cases is still a major operative challenge, we believe that improved treatment protocols can be of an aid to the orthopedic trauma surgeons. Double, orthogonal plating with preservation of blood supply with or without bone grafting provide such a solution. The same principles can be applied to various anatomical locations.

CONCLUSION

Orthogonal plate fixation is a viable option for treating stubborn non-union cases including chronically infected ones. The mechanical and biological advantages especially when using locking plates are numerous and should be applied with proper surgical technique.

References

1. AMIR, M., LEWIN-EPSTEIN, N., BECKER, G., et al.: Psychometric properties of the SF-12 (Hebrew version) in a primary care population in Israel. Med. Care, 40: 918–928, 2002.
2. BARBIERI, C. H., MAZZER, N., ARANDA, C. A., et al.: Use of a bone block graft from the iliac crest with rigid fixation to correct diaphyseal defects of the radius and ulna. J. Hand Surg., (Edinburgh, Scotland) 22: 395–401, 1997.
3. BINKLEY, J. M., STRATFORD, P. W., LOTT, S. A., et al.: The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. North American Orthopaedic Rehabilitation Research Network. Phys. Ther., 79: 371–383, 1999.
4. DAHABREH, Z., DIMITRIOU, R., GIANNOUDIS, P. V.: Health economics: a cost analysis of treatment of persistent fracture non-unions using bone morphogenetic protein-7. Injury, 38: 371–377, 2007.
5. FAROUK, O., KRETTEK, C., MICLAU, T., et al.: Effects of percutaneous and conventional plating techniques on the blood supply to the femur. Arch. Orthop. Trauma Surg., 117: 438–441, 1998.
6. FAROUK, O., KRETTEK, C., MICLAU, T., et al.: Minimally invasive plate osteosynthesis: does percutaneous plating disrupt femoral blood supply less than the traditional technique? J. Orthop. Trauma, 13: 401–406, 1999.
7. FRIEDRICH, B., KLAUE, P.: Mechanical stability and post-traumatic osteitis: an experimental evaluation of the relation between infection of bone and internal fixation. Injury, 9: 23–29, 1977.
8. HELFET, D. L., HOTCHKISS, R. N.: Internal fixation of the distal humerus: a biomechanical comparison of methods. J. Orthop. Trauma, 4: 260–264, 1990.
9. HÜBNER, E. J., HAUSSCHILD, O., SÜDKAMP, N. P., STROHM, P. C.: Clavicle fractures – is there a standard treatment? Acta Chir. orthop. Traum. čech., 78: 288–296, 2011.
10. CHAPMAN, M. W., GORDON, J. E., ZISSIMOS, A. G.: Compression-plate fixation of acute fractures of the diaphyses of the radius and ulna. J. Bone Jt Surg., 71-A: 159–169, 1989.
11. JUPITER, J. B., WYSS, H.: Stable fixation of osteoporotic fractures and nonunions in the upper limb – life before the „locking plate“. Acta Chir. orthop. Traum. čech., 77: 361–364, 2010.
12. KABAK, S., HALICI, M., TUNCEL, M., et al.: Treatment of midclavicular nonunion: comparison of dynamic compression plating and low-contact dynamic compression plating techniques. J. Shoulder Elbow Surg. / Am. Shoulder Elbow Surg., 13: 396–403, 2004.

13. KNIGHT, R. A., PURVIS, G. D.: Fractures of both bones of the forearm in adults. J. Bone Jt Surg., 31-A: 755–764, 1949.
14. LARSON, A. N., RIZZO, M.: Locking plate technology and its applications in upper extremity fracture care. Hand Clin., 23: 269–78, vii., 2007.
15. LEE, Y. S., LIN, C. C., HUANG, C. R., et al.: Operative treatment of midclavicular fractures in 62 elderly patients: knowles pin versus plate. Orthopedics, 30: 959–964, 2007.
16. O‘DRISCOLL, S. W.: Optimizing stability in distal humeral fracture fixation. J. Shoulder Elbow Surg. / Am. Shoulder Elbow Surg., 14: 186S-194S, 2005.
17. PRASARN, M. L., AHN, J., ACHOR, T., et al.: Management of infected femoral nonunions with a single-staged protocol utilizing internal fixation. Injury, 40: 1220–1225, 2009.
18. PRASARN, M. L., OUELLETTE, E. A., MILLER, D. R.: Infected nonunions of diaphyseal fractures of the forearm. Arch. Orthop. Trauma Surg., 130: 867–873, 2010.
19. RING, D., PEREY, B. H., JUPITER, J. B.: The functional outcome of operative treatment of ununited fractures of the humeral diaphysis in older patients. J. Bone Jt Surg., 81-A: 177–190, 1999.
20. ROCHET, S., OBERT, L., LEPAGE, D., et al.: Proximal ulna comminuted fractures: Fixation using a double-plating technique. Orthop. Traumatol. Surg. Res., 96: 734–740, 2010.
21. RUBEL, I. F., KLOEN, P., CAMPBELL, D., et al.: Open reduction and internal fixation of humeral nonunions : a biomechanical and clinical study. J. Bone Jt Surg., 84-A: 1315–1322, 2002.
22. SANCHEZ-SOTELO, J., TORCHIA, M. E., O‘DRISCOLL, S. W.: Complex distal humeral fractures: internal fixation with a principle-based parallel-plate technique. J. Bone Jt Surg., 89-A: 961–969, 2007.
23. SANCHEZ-SOTELO, J., TORCHIA, M. E., O‘DRISCOLL, S. W.: Complex distal humeral fractures: internal fixation with a principle-based parallel-plate technique. Surgical technique. J. Bone Jt Surg., 90-A (Suppl 2 Pt 1): 31–46, 2008.
24. SELF, J., VIEGAS, S. F., BUFORD, W. L., Jr., et al.: A comparison of double-plate fixation methods for complex distal humerus fractures. J. Shoulder Elbow Surg. / Am. Shoulder Elbow Surg., 4: 10–16, 1995.
25. SHEN, J. W., TONG, P. J., QU, H. B.: A three-dimensional reconstruction plate for displaced midshaft fractures of the clavicle. J. Bone Jt Surg., 90-B: 1495–1498, 2008.
26. SPITZER, A. B., DAVIDOVITCH, R. I., EGOL, K. A.: Use of a „hybrid“ locking plate for complex metaphyseal fractures and nonunions about the humerus. Injury, 40: 240–244, 2009.
27. WAGNER, M.: General principles for the clinical use of the LCP. Injury, 34 (Suppl. 2): B31–42, 2003.
28. WEBER, B. G., CECH, O.: Pseudarthrosis. Grune and Stratton: New York; 1976, 104.
29. WERESH, M. J., HAKANSON, R., STOVER, M. D., et al.: Failure of exchange reamed intramedullary nails for ununited femoral shaft fractures. J. Orthop. Trauma, 14: 335–338, 2000.
30. WINQUIST, R. A., HANSEN, S. T., Jr., CLAWSON, D. K.: Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. J. Bone Jt Surg., 66-A: 529–539, 1984.
31. WORLOCK, P., SLACK, R., HARVEY, L., et al.: The prevention of infection in open fractures: an experimental study of the effect of fracture stability. Injury, 25: 31–38, 1994.
32. YOUNG, J. P., STOVER, M. D., MAGOVERN, B.: Treatment of isolated ulnar nonunions using wave plate osteosynthesis: a report of four cases. J. Orthop. Trauma, 23: 595–599, 2009.

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