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Principles and Clinical Application of the Locking Compression Plate (LCP)

Zásady a klinické použití uzamykatelné kompresní dlahy LCP

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SUMMARY

The principle of the locking compression plate (LCP) is represented by the combination of two completely different anchorage technologies and two opposed principles of osteosynthesis in one implant it combines the principles of conventional plate osteosynthesis for direct anatomical reduction with those of bridging plate osteosynthesis. Since the LCP can be used as a conventional plate using only dynamic compression, as a pure internal fixator using locking head screws, or as both combined, it provides the surgeon with multiple variations. Nevertheless, these new possibilities mean that preoperative planning and an understanding of the different biomechanical principles of osteosynthesis are essential if good clinical outcomes are to be achieved and maximum benefit is to be attained from the options offered by the LCP system.

The current article provides biomechanical background to and guidelines for the use of LC plates in the operative treatment of fractures and also reports experimental and clinical results obtained with LCP.

INTRODUCTION

Since the first instance of internal fixation with a plate (carried out by Hansmann in Hamburg in 1886 (8) and the later integration of this principle into operative fracture treatment as a result of Lambotte's work, both the implants used and the related principles of fracture treatment have been in a state of continuous development.

While in the early years of internal fixation with plates various principles were pursued in parallel, the standardization of the indications for and techniques of internal fixation with compression plates by the Swiss Association for the Study of Internal Fixation (ASIF) was one of the achievements of the 1950s that were later taken further by the Working Group on Matters Concerned with Internal Fixation (AO). The object of the technique of operative treatment of fractures with compression internal fixation described in the first edition of the AO Manual of Internal Fixation was thus stable internal fixation with the purpose of giving the bone primary strength to allow ;early functional mobilization it was intended that this should be achieved by applying the principle of interfragmentary compression with the object of absolute stability. The dynamic compression plate (DCP) was developed to realize this objective of internal fixation, and it allowed axial compression of the fracture zone by way of eccentric drilling for compression screws. In keeping with this principle, such an internal fixation operation led to primary bone-fracture consolidation without visible callus formation. Conventional plating methods are based on the use of an adequate number of anchoring screws to press the plate against the bone with high compressive forces, creating a stable bone-implant connection. When this technique is used, biocortical screws yield the best possible anchoring force. Even tiny fragments were adapted in the course of this interfragmentary compression, which required wide exposure of the fracture zone. Denudation of the individual fragments and exposure of the fracture zone consequently led to increased rates of infection, nonunion, and delayed healing, owing to lacking bone and soft tissue vitality.

During the 1980s, the principle of absolute stability through interfragmentary compression, which is still valid today in the operative treatment of joint fractures, was increasingly reconsidered against the backdrop of the raised complication rates for osteosynthesis with compression plate systems performed to treat diaphyseal fractures. Not the smallest factor in these considerations was that of the outcomes obtained with medullary nailing, a technique that led to satisfactory treatment results by way of secondary bone healing with callus formation though absolute stability was not achieved. Logically, this led to the concept of internal fixation with bridging plates (1, 7) for the treatment of diaphyseal fractures. According to this principle, the fracture zone of fragmented fractures of a shaft or metaphysis remains undisturbed during surgery following realignment taking account of the axis, length, and rotation, and the bridging plate is anchored in the main fragments proximal and distal to the fracture. In contrast to conventional internal fixation, then, this form of internal fixation yields only relative stability and the secondary bone healing with callus formation is thus no

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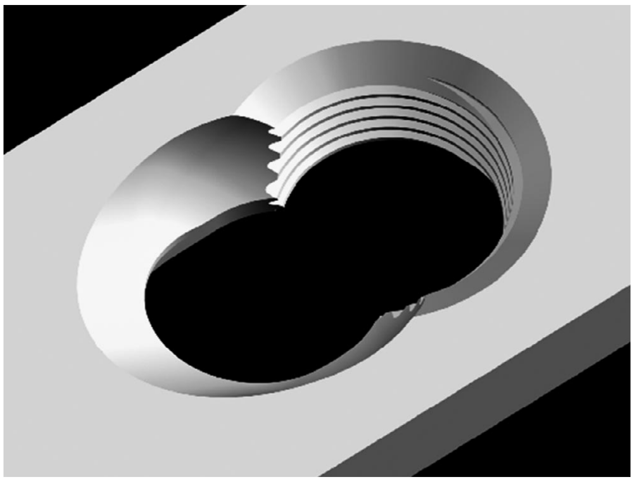

Figure 1. Combination hole as principle of the LCP gives surgeons the opportunity to combine principles of internal fixation and dynamic compression, depending on the fracture site.

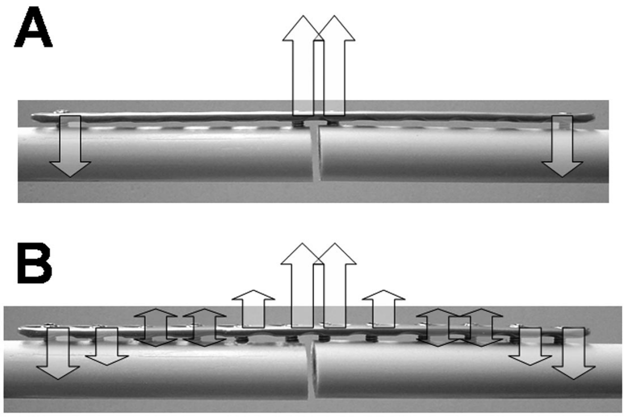

Figure 2. Analysis of forces in dependence of the screw number shows different distribution of bending forces with minimal number of screws (A) and maximal number of screws (B).

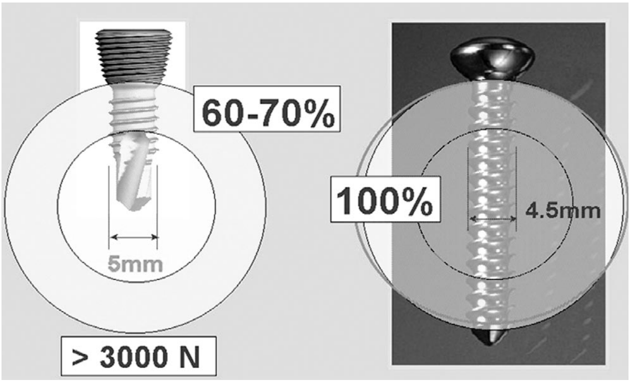

Figure 3. Analysis of pull out forces reveals 70% holding force in a monocortical locking head screw (LHS) compared to a 100% of the holding force of a conventional bicortical 4.5 mm screw.

longer an undesirable side-effect, but rather the object of treatment. The nonexposure of the fracture zone means that additional devascularization of bone fragments is avoided. In view of this, the term „biological plate osteosynthesis“ has been introduced for bridging internal fixation (1, 18).

Principle and Development of the Locking Compression Plate

The revolutionary new aspect of the locking compression plate (LCP) is the combination of two completely different anchorage technologies in one implant.

Development of the LCP principle is based on experience gained with the PC-Fix and LISS systems. In contrast to these systems, the LCP with combination holes gives surgeons the opportunity to combine principles of internal fixation and dynamic compression, depending on the fracture site. The LCP can be used as a compression plate, a locked internal fixator, or a combination of both, depending on the patient's individual situation (4, 16).

Application of LCP

Relative to conventional plate osteosynthesis, the new generation of LCP requires an adaption to the surgical technique. The importance of the reduction technique and minimally invasive plate insertion and fixation relates to ensuring that bone viability is undisturbed. Understanding of the biomechanical background of bridging plate osteosynthesis is essential if good clinical results are to be obtained. Most of the pitfalls encountered by surgeons using the LCP system have nothing to do with the implants and must be attributed to nonobservation of important basic principles of the concept of biological osteosynthesis (24). These principles are summarized below.

Length of the LCP

One of the most important steps in the application of LCP is selection of plates of appropriate length. The lesser soft tissue trauma resulting from the less extensive exposure of the bone has been seen as a reason for using short plates in the past with conventional plating systems, but this no longer applies when LCP are used. In this case longer plates can be selected without associated traumatization of the soft tissues, and the length selected needs to take account only of the biomechanical situation in the fracture. When the internal fixation is planned the object should be to keep plate loading, which is influenced by both the length of the plate and the placement of the screws, as low as possible. In the case of LCP the ideal plate length can be determined by the plate span width and the plate screw density (20): the plate span width is the quotient of plate length divided by overall fracture length. This quotient should generally be more than 2-3 for comminuted fractures and higher than 8-10 in the case of simple fractures (6).

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Number and Positioning of Screws

A second value is of equal importance: screw density (quotient of screws inserted divided by number of plate holes). Experience has shown that this value should be under 0.4-0.5. In contrast to conventional plate osteosynthesis, when LCP are used it is no longer possible to recommend a definite number of screws or cortices to be used in each fragment. Anchorage in the main fragments proximal and distal to the fracture zone remains important nevertheless, it is much more important that the number of screws inserted is as small as is consistent with the provision of high plate leverage so that screw loading is kept low. Two monocortical screws should be the minimum for each main fragment, to keep the construct stable. For safety reasons, we generally recommend two to three screws per main fragment, so that stability will be ensured even if insertion of one of the screws is less than optimal. The use of biocortical screws in each fragment does not improve the situation from the aspect of screw failure, but does improve that of the interface between screw and bone, and it is therefore recommended that at least one of the screws in the main fragment (6) should be a biocortical screw. Axial pullout of the screws is determined by the outer diameter of the screw. An increase from 4.5mm (conventional cortical screw) to 5.0mm (Locking Head screw) provides already 70% holding force in a monocortical Locking Head screw (LHS) compared to a 100% of the holding force of a conventional bicortical 4.5mm screw.

The positions of the screw holes actually used relative to the fracture are also very important when LCP are used. Dynamic loading tests have shown that in the case of fractures where there is no bone contact between the main fragments (comminuted fractures), when screws are not inserted in the holes at each side of the fracture, with an effective increase in the length of bone bridged**,** this leads to premature failure of the implant. In these biomechanical tests, plate failure was regularly found to occur at the DCP screw hole on which finite element analysis revealed the most intense Misse stresses (27). Such stress is reduced by increasing the bridging length, since the forces are distributed over a larger area of the plate. In the case of simple fractures with bone contact when fracture spaces are small this is not a problem. On the other hand, additional screws increase the stress on the implant, as greater loads are required to achieve bone contact (27). On the basis of these results, it can be recommended that in the case of simple fractures where there is bone contact one or two combination holes be left unused on each side of the fracture space, while in the case of complex fractures with an extensive fragmented zone and resultant lack of bone contact the holes closest to the fracture should be used. A small interval between plate and bone also causes attenuation of the leverage exerted on the bone-implant complex, while a sufficiently long plate increases the axial rigidity, as mentioned above (6). However, an aiming device should be used in every case during drilling for the locking head screws, since axial deviation of the direction of drilling by more than 5° leads to significantly impaired stability (10).

The principles detailed above apply to bridging osteosynthesis to be performed for correction of diaphyseal and metaphyseal fractures. In the case of meta-epiphyseal fractures this principle can be deviated from insofar as the combination holes in the area of the joint allow anatomical realignment and internal fixation in keeping with the principle of interfragmentary compression, while at the same time the metaphyseal region can be well served by a bridging osteosynthesis. The number of screws in the area of the joint depends solely on the object of refixation with interfragmentary compression. This combination of two different principles of internal fixation in a single implant is one of the main advantages of the LCP. In cases where both – conventional screw and locking head screws are applied – it is necessary to apply the LHS after the conventional screw. If the conventional screw would be applied after the LHS, the screw – bone interface would be overloaded and the screw would be worthless.

Shaping of the LCP

In conventional plate osteosynthesis, stability is provided by adapting the implant to the bone. The screws are used to apply a compressive preload at the interface between plate and bone. This means that accurate shaping of the plate is essential. When the LCP is used as an internal fixator, exact adaptation of the implant to the bone surface is not necessary. Nevertheless, even in the case of diaphyseal fractures it can be beneficial to bend the plate between the screw holes in such a way as to ensure that the different screws face in different directions, increasing resistance to detachment in keeping with the principle of polyaxial anchorage. This is of most benefit in bone affected by osteoporosis. It is also beneficial to bend the LCP in the area of the metaphysis, though in this case no more than a rough adaptation is necessary, to prevent an extreme amount of space between the plate and the bone. This ensures less stress on the soft tissue and also leads to diverging directions of the screws, affording increased resistance of the osteosynthesis to detachment.

Anatomically Preshaped LCP

Since it is not necessary for the plates to be tailored precisely to the bone for each patient, in the further course of the LCP's development preshaped plates were devised for use in fractures in various anatomical regions. This plating system has been supplemented by preshaped LCP implants that can be used in the case of corrective osteotomies close to joints. Preshaped plates have several advantages: intraoperative shaping is no ;longer required the plate systems themselves help in achieving anatomical reduction, and aiming blocks help in insertion of the locking head screws. In addition, there

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Figure 4. Distal tibia LCP for the treatment of lower leg fracture (AO type 43 A2). While principles of conventional plate osteosynthesis were used for the treatment of the distal fibula fracture, minimal invasive plate osteosythesis (MIPO) using principles of bridging plate osteosynthesis were applied for the treatment of the distal tibia fracture.

is a defined placement for each of the given plates and clear rules on how to use each, which are expected to lead to more standardized procedures.

These preshaped LCP systems for various anatomical regions have been introduced into clinical practice in addition to the basic, straight 3.5- / 4.0-mm and 4.5- / 5.0-mm LCP systems and the T- and L-plates. The 3.5- / 4.0 mm and the 4.5-/5.0-mm LCP are also available for use as reconstruction plates. One purpose the last is suitable for is internal fixation in the region of the symphysis pubis.

The following preformed LCP systems are currently available. The PHILOS plate is a system that has already proved its worth in clinical practice for use in the region of the proximal humerus, and it is available in a short version with two different lengths (with 2 and with 8 combination holes). The distal humerus LCP is available for distal fractures of the humerus. In addition to the conventional 3.5-mm T-plate, the 2.4-mm LCP system for the distal radius is an option offering advantages over the larger 3.5-mm system in the case of small epiphyseal fragments. For applications in the hand a number of special plates with combination holes are available, which are subsumed under the LCP compact hand system. An anatomically preformed LCP has been introduced to supplement the LISS system for correction of distal fractures of the femur in the vicinity of the knee, and an analogous system, the LCP proximal tibia system, for proximal fractures of the tibia and fractures of the tibial head. Two alternates are available for osteosynthetic treatment of fractures of the distal tibia: the distal tibia LCP and the pilon LCP. The latter is characterized by a larger number of alternate holes in the region of the distal epiphysis of the tibia, which makes the treatment of depression fractures of the distal tibia easier. The LCP system for treatment of fractures of the lower extremities is also supplemented by the LCP metaphysis plate for distal medial tibia (a 12-hole LCP), the LPC condyle plate (applied, for example for internal fixation of the metatarsals), and the wide, arched LCP, which is available in several lengths and is useful (for example) in the treatment of periprosthetic fractures, or also following knee arthrodesis, because it takes account of the actual retrocurvature of the femur, thus allowing all the screws to be centrally anchored in the bone when the plate is fixed laterally (6).

Biomechanics – In Vitro Studies

The biomechanical properties of the LCP were thoroughly studied before the system was introduced into clinical use (27, 29). Nevertheless, in parallel with the first clinical evaluation studies a number of additional studies were conducted, and these confirmed the initial results of biomechanical testing prior to clinical application and reemphasized the advantages of the LCP system over conventional fixation systems for special applications.

In an experimental cadaveric model of a C2 radius fracture, the palmar locking compression T-plate proved to yield better stability than conventional plating systems (13). The LCP was found to be mechanically supe-

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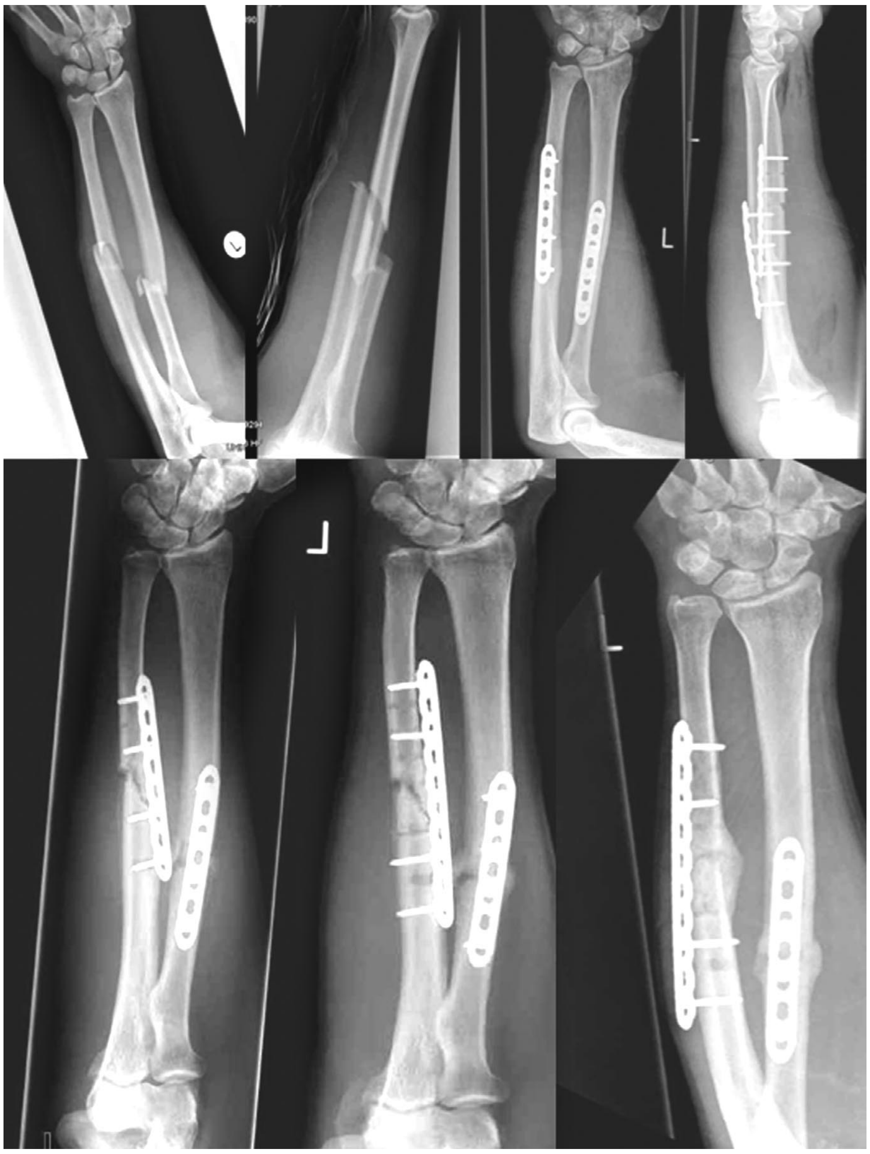

Figure 5. 3.5 / 4.0mm LCP used for the treatment of a forearm fracture (AO type 22 A3). In this case non-union of the ulna shaft fracture (lower left image) was observed 5 months after initial open reduction and internal fixation (ORIF) using 8-hole 3.5 / 4.0 mm LCP (upper right image), since principles of bridging osteosynthesis have not been applied adequately in terms of a correct positioning of the inner screws which have been placed too close to the fracture site. After revision using a longer LCP (10-holes 3.5 / 4.0 mm LCP) including a change of inner screw positioning (lower mid), bridging length increased and consolidation of the fracture could be achieved within further 3 months after revision surgery (lower right image).

rior to the LC-DCP in terms of both antero-posterior stability and torsion in a cadaveric study on the distal radius conducted by Gardner (5). Additionally, in other experimental work, such as a biomechanical examination of plating systems used for the treatment of distal humerus fractures, the LCP system proved to be reliable in achieving primary stable fracture fixation (11). In the proximal humerus, the elasticity of the LCP-PH even seems to lead to load reduction in terms of reduced peak stress at the bone-implant interface, which results in a significantly lower rate of early loosening in weak bone than when rigid implants that provide higher initial stiffness are used (14). In another in vitro experimental study in an equine long bone fracture model, LCP constructs showed the best performance because they had the highest yield strength above which irreversible deformation occurred in this study the LCP system was compared against a clamp-rod internal fixator and the LC-DCP (2). Although these studies provide consistent evidence for the biomechanical superiority of the LCP, it must be mentioned that there have been other well-designed studies that have not revealed any biomechanical advantage of the LCP system over conventional plating systems, such as that performed by Trease's group, who compared locked and nonlocked palmar and dorsal osteosynthesis of the distal radius (28). Nevertheless, not a single study has revealed any biomechanical disadvantage of the LCP system against conventional plating systems.

CLINICAL RESULTS

Since the introduction of the LCP in 2001, various papers have dealt with clinical results obtained with this osteosynthesis system. Overall, satisfactory results have been reported for all published studies. The first clinical study, involving 169 patients treated with LCP, was published by Sommer in 2003, and the authors came to the conclusion that the new system could be regarded as technically mature, since the majority of the patients

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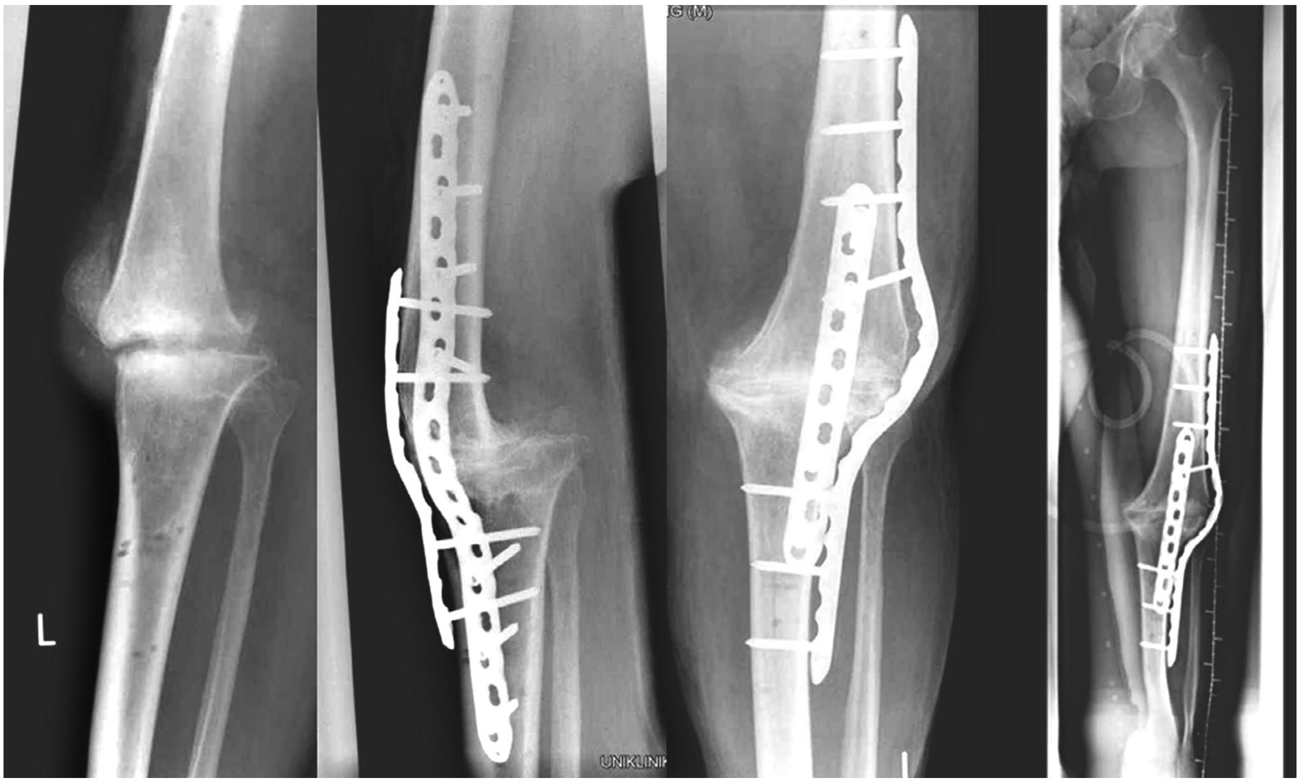

Figure 6. Case of a non-union after arthrodesis of the knee joint using external fixateur following removel of the revision knee prosthesis due to chronic infection. Bended 20-hole 4.5 / 5.0 mm LCP was used in combination with autogenous cancellous bone graft and additional 10-holes 4.5 / 5.0 mm LCP to achieve union of the arthrodesis within 6 months after surgery.

reported good to excellent clinical outcomes. The numerous options it offers for fixation had made it especially valuable in complex fracture situations and in revision operations after other implants had failed (25). One of the commonest fracture localizations in which the LCP system is used is the distal radius. In contrast to the earlier assumption that open reduction and internal fixation by a dorsal approach is the best policy in cases of dorsally displaced fractures of the distal radius, it has been found that palmar locking plates are safe and effective implants for use in the treatment of dorsally displaced fractures of the distal radius, avoiding any damage to the dorsal extensor s (22). When 2.4-mm LC plates were used good or very good results were obtained even in over 80% of distal radial fractures in osteoporotic bone. Nevertheless, relative to other treatments, intervention with LC plates involves much higher real costs (21). This cost factor is offset by the great advantage of the palmar fixed-angle plate system, which is that the early active movement throughout the range can be facilitated without compromising fracture reduction (15). Good results were also reported by Imatani following the treatment of metaphyseal radius fractures (9).

In further studies LC plates have been successfully used for the treatment of transverse fractures of the sacrum or sternum (23), of periprosthetic fractures (3), and also of fractures and osteoporotic nonunions of the distal humerus (11, 12, 19).

The good clinical results published so far should not blind us to the fact that complications can still arise even when LCP are used. In the studies hitherto available, the complications have not been attributable to implant failure so often as to nonobservation of the principles of bridging osteosynthesis. These complications make it plain that both a good knowledge of biomechanics and precise preoperative planning are essential if the use of LCP systems is to be successful (24).

A particular feature of the application of LC plates that impressed the patients in our population is a tendency to delayed fracture consolidation. Especially in cases in which too little account is taken of the principle of biological, i.e., bridging, osteosynthesis, the stability of the LCP system might lead to delayed fracture healing, as we observed in some cases of forearm fracture, for example. Analogous observations have been reported following open wedge osteotomies of the proximal tibia (26). Nevertheless, the percentage of cases with delayed union and/or delayed fracture healing seems to be low.

CONCLUSION

The development of the LCP, which has been available for clinical use since 2001, has revolutionized internal plate fixation insofar as this system combines two different principles of internal fixation, each of which

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has advantages in specific situations. Thus, a single implant gives the surgeon access to the entire range of options for internal fixation, from compression screw osteosynthesis with the principle of absolute stability to „biological," i.e., bridging, osteosynthesis with relative stability. These combination options do, however, mean that accurate knowledge of the characteristics of the various principles of internal fixation is essential. The anatomically preshaped plates make it easier for the surgeon to select from the different combinations possible by prescribing the typical type of internal fixation for each segment of the skeletal system. This is intended to help surgeons to reduce the incidence of complications such as were observed in the early years of application of the LCP as a result of nonobservation of the principles of osteosynthesis and to exploit all the options offered by the LCP system. Nonetheless, against the backdrop of the preclinical and clinical data available at present, we can conclude that the LCP system is a reliable and safe tool that extends the options open for internal fixation by plating and has advantages over other systems in terms of the stability that can be achieved with it especially in osteopenic or osteoporotic bone (17).

ZÁVĚR

Pokroky ve využívání uzamykatelné kompresní dlahy LCP, která je dostupná pro klinické využití od roku 2001, znamenají převrat v technikách vnitřní fixace pomocí dlah. Tento systém spojuje dva odlišné principy vnitřní fixace, z nichž každý má své výhody v určitých situacích. Jediný implantát tady dává chirurgovi přístup k celé škále možností vnitřní fixace, od osteosyntézy pomocí tahových šroubů, založené na principu absolutní stability, k „biologické", tj. přemosťující osteosyntéze s relativní stabilitou. U těchto kombinovaných možností je však bezpodmínečným předpokladem dobrého provedení dokonalá znalost charakteristik různých principů vnitřní fixace. Předem anatomicky formované dlahy usnadňují chirurgovi výběr z možných kombinací tím, že předurčují specifický typ vnitřní fixace pro každý segment kosterního systému. To pomáhá chirurgům snížit výskyt takových komplikací, jaké jsme např. pozorovali v prvních letech používání LCP právě z důvodů nedodržování principů osteosyntézy, a umožňuje jim využít všech možností, které LCP systém poskytuje. Na pozadí preklinických a klinických údajů dostupných v současné době můžeme učinit závěr, že LCP systém je spolehlivý, bezpečný a rozšiřuje možnosti vnitřní fixace pomocí dlah. Oproti jiným systémům má výhody v tom, že umožní dosáhnout stability i u pacientů s osteopenií nebo osteoporózou.

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Práce byla přijata 2. 5. 2006.