Biomechanical and Biological Aspects of Defect Treatment in Fractures Using Helical Plates

Biomechanické a biologické aspekty léčení defektních zlomenin s využitím helikálních dlah

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INTRODUCTION

The clinical case of figure 1 through figure 11 shows a series of impressive failures of plate fixation. The plates were repeatedly applied bridging a comminuted bone segment in a heavy patient. The biomechanical analysis elaborates why this happened and proposes an unconventional procedure to prevent this failure with a minimally invasive procedure.

A plate bridging an open gap or a defect in a long bone diaphysis is exposed to full functional load. According to clinical observations such plate application often fails even without external load such as weight bearing. The plate risks to break through fatigue when exposed during a long time to cyclic loading. This type of failure has been observed even with broad plates as well in femoral as in tibiae.

The first option to avoid such failure consists in protecting the plate by installing load sharing between plate and either bone or an additional implant. This reduces the load carried by the plate to a safe level. Load sharing with bone may be installed at surgery by establishing solid mechanical bridge between the two main fragments of the fractured bone. The optimal load sharing

Fig. 1. Young adult, obese female, BMI 37. Ipsilateral femoral neck and segmentally comminuted mid-shaft fracture. Clinically the neck fracture requires attention by priority because of more demanding complications. Here the biomechanical analysis is limited to the femur shaft fracture with segmental comminution and no contact and/or support between the two main fragments.

Fig. 2. Short DHS, and bridging 13 hole round hole broad lateral steel plate. Free span 5 holes long, no contact of main fragments, full functional load placed on plate.

Fig. 3. Plastically deformed plate, varus 30 deg. The plate will eventually break due to cyclic bending load if left alone.

Fig. 4. Anterior broad DCP, this orientation and position will offer better strength in respect to varus/valgus bending. Cortical bone graft adapted with only three cerclages. The leverage of the cerclages is insufficient. The cortical bone graft does not add stability until bony integration. The latter is not to be expected because of loose coupling.

Fig. 5. Cyclic bending load produces enough deformation to break the screws, despite some progress of healing. The fracture area gave way in spite of some but insufficient bone formation. The latter did not alleviate sufficiently bending load exerted on the plate. The screws broke. Rotational deformity. The proximal cerclage opened.

Fig. 6. New lateral 12 hole LCP with locked screws. The thick core screws which provide better strength against screw bending. The proximal end of the long plate overrides the DHS. The increased distance bone to plate increases the torsional load .

relies on a solid compressed contact between the main fragments. It can be established because the bone is able to take a large load which results in optimal protection of the plate. In the case of an extended comminuted bone segment it may be very difficult, traumatizing and inefficient to reconstruct the bone. In the present case it was impossible to establish load sharing through the bone.

The second option protecting the plate is provided by callus bridging of the gap or defect. The formation of a solid callus bridge takes time but the fatigue failure of the plate also takes time. Therefore, the callus bridge may prevent a late fatigue failure.

The surgeon may select one of several options:

- Replacing the lack of bone support using a second plate which immediately alleviates plate loading. The drawback of application of a second conventional plate is the extent of surgical trauma at the critical site of healing.
- Shingling and/or applying an autologous cancellous bone graft: This procedure provides initially no relevant load sharing but will do so after a couple of weeks. The mechanical coupling of the comparably soft graft and the main fracture fragments presents little problems.

Applying a cortical bone graft: Such a graft does provide initial only small load sharing and does a less good job inducing callus than a cancellous graft. Furthermore, the coupling by callus between a somewhat rigid bone graft and the mobile main fracture fragments requires a solid maintained contact. If the cortical graft is fixed using implants with small contact area to the graft such as screws or cerclage loops, the local stress may be critical and the graft may break. When the cortical graft is fixed with cerclage wires the procedure must take into account the limited strength of the individual cerclage. Therefore multiple and well-spaced cerclages are required and may lead to success especially if an intramedullary component of the implant contributes to protection (6).

The degree of unloading depends apparently on the stiffness of the material of the protecting splint. Though, more important is the effect of the dimensions of the splint. While titanium as a material is about 50% less stiff than steel, the thickness of the implant changes the stiffness with the third power. That is doubling the thickness results in eightfold increased stiffness. When considering the unloading by application of a second plate the leverage of the second plate plays an important role. The larger the distance between the axis of bending and the second implant the larger the protecting effect.

The helical plate (2, 3, 7) as introduced by A.A.D. Fernandez offers biological and mechanical advantages. It can be applied without touching the fracture site maintaining the critical biology intact and provides mechanically efficient unloading. Its application is fairly simple:

The helical plate is modified conventional long and small plate that is twisted between its ends about 90 degrees. The twist is applied using "bending irons" (4, 5, 8) whereby the force required is small and the exact degree of twist is not critical. Therefore the twist is applicable operating bending irons by hand.

Assuming a situation where a plate bridging a defect or non-union has failed the broken plate is replaced by a similar implant: At the distal end of the bone fracture and opposite to the surgical approach a small incision allows to slide in the helical plate in such a way that proximally the plate ends on the same side of the limb as the replaced plate. Ideally the two plate ends meet and the application of the helical plate does not ask for an additional surgical exposure at this location. Otherwise a small minimally invasive exposure is required. The helical plate is then fixed to the main bone fragments using a couple of locked screws.

The following case demonstrates the use and efficiency of the helical plate saving a situation where multiple attempts using conventional plates had failed. The successful final treatment of this case was performed by A. A. D. Fernandez.

DISCUSSION

The problems and a possible solution of treating a comminuted segmental defect in mid-shaft of the femur are discussed from a biomechanical viewpoint. The question whether one should use a nail or plate, as well as whether there should be a bone graft and/or shingling should be used are not addressed here.

A plate spanning a defect in a long bone diaphysis requires special care to avoid fatigue failure. This also applies to some situations of delayed- or non-union when callus is produced but it cannot solidly bridge the fracture or when callus is absent. Therefore, the treatment options after initial plate fixation of a defect avoiding implant failure are:

- Unloading through reduced weight bearing is demanding and inefficient.
- Increasing stiffness implanting a second conventional plate. Two aspects:
  - large surgical approach needed,
  - double plating was an issue for years, less so now.
- Increasing stiffness using a fixator extern, not a solution for a long lasting treatment, awkward and problematic (e.g. pin track infections).

Fig. 7. Medial heavy callus bridge with proximal discontinuity, main fragment ends appear as "atrophic" in contact. Screw failures, some breakages some pullout. The callus bridge could not unload the plate as it did not provide a continuous bridge between both main fragments.

Fig. 8. LCP 16 hole. The short free span for a given deformation increases risk of plate breakage. Frustrated healing.

Fig. 9. Now the screws held but plate broke

– Increasing stiffness with minimal surgical trauma sliding in the helical plate.

Provided the plate spanning the defect failed a replacement and addition of a helical plate is a solution worth more than just considering.

The helical plate is a straight plate slightly twisted. The helical shape allows to slide in the plate with only a small additional incision distally and using the same original surgical approach at its proximal end. The application of the helical plate strongly stiffens a construct and improves strength in respect to bending. It is also indicated when an internal plate fixation lacks required rigidity and thus prevents prompt healing and/or is painful.

The helical plate provides additional stiffness reducing fracture mobility in respect to bending around an axis perpendicular to the long axis of the original plate and it's flat surface. In respect to this bending the helical plate provides a substantial increase of stiffness due to its efficient leverage based on the large distance from the fulcrum of bending in the original plate.

The application of the helical plate obviates damage to the blood supply of the bone because it is inserted according to minimal invasive plate fixation (MIPO) (1, 19938) avoiding biologic damage to the fracture or non-union site.

The discussed application of treatment of defect situation is but one aspect of the helical plate fixation. In fracture treatment of the humerus is the different axis of the screws applied in the main fragments is a definite surgical advantage (4, 9). The helical plate may also be used to protect a plate fixation from the beginning on. The reduced mobility together with a wide fracture gap may then result in very low strain and with it in slow healing whereby the full pain-free function fulfills the requirement of the surgical fracture fixation. The slow healing is an aspect without functional importance but not emotionally attractive.

It goes without saying that the x-ray appearance of fracture treatment using a helical is unconventional to say the least. Still real progress is usually non-conventional.

CONCLUSION

Several attempts to stabilize a segmental comminution failed through plate and/or screw breakages. The final successful one step treatment demonstrates that application of proper principles exceeds by far the effect of using heavy implants.

In spite of its highly unconventional appearance the potential of the helical plate deserves careful consideration because the helical plate adds stiffness and strength maintaining biology, thus allowing healing with early pain free weight bearing. The biomechanical aspects of helical plate fixation require further studies for optimal understanding and with it best application.

Fig. 10. New LCP steel plate same position, why should this plate not break considering the experience with similar plating in the same patient?

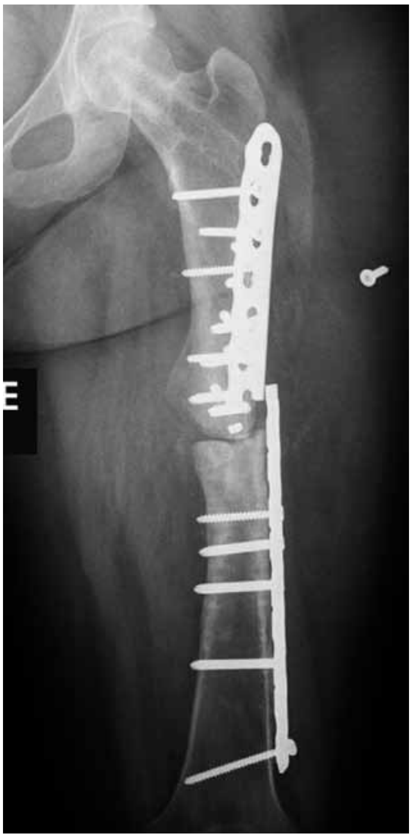

Fig. 11. One more plate failure.

Fig. 12. Plate exchanged, fracture gap approximated to less than 1mm using the removable compressor resulting in some bony support. Adding the helical plate markedly reduces the bending load.

Fig. 13. At 9 weeks. With the rigid fixation one can expect the callus to be able to bridge with good coupling. Full, pain-free, weight bearing.

Fig. 14. At 25 weeks. Solid healing no sign of mechanical failure. Good structure of bone in distal fragment.

Fig. 15. At 39 weeks correct alignment of axis, shortening. No plate breakage proves good unloading of plate by helical plate. After many failed attempts of plate fixation the helical plate offers a successful one step procedure.

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