3.1.3 Minimally invasive surgery

1 Introduction

Minimally invasive procedures with limited surgical trauma to soft tissues and bone have been applied to fracture management for a long time. Small approaches and indirect reduction techniques without exposure of the fracture focus have biological advantages not only for fracture healing but also for the whole body, as demonstrated by damage-control surgery in the polytraumatized patient. Closed intramedullary nailing of diaphyseal fractures using short incisions and indirect reduction usually results in undisturbed fracture union by callus formation. Early advocates of biological osteosynthesis by bridge plating [1, 2] demonstrated that when indirect reduction was combined with internal splinting with long plates for fractures of the epi-/metaphysis extending into the femoral shaft, there was a similar pattern of undisturbed bone healing with callus formation as with intramedullary nailing, regardless of the length of incision.

For the anatomical reconstruction of articular fractures the approach must be large enough to give an adequate view of the joint surfaces; only in simple split fractures may we attempt arthroscopic control.

With these considerations in mind, Krettek et al [3] started to combine the principle of ORIF for the articular segment in a complex distal femoral fracture with minimally invasive, submuscular tunneling along the diaphysis for the insertion of a long bridging plate. The introduction of the less invasive stabilization system (LISS) for distal femoral (chapter 6.6.3) and proximal tibial fractures (chapter 6.8.1) opened new possibilities for minimally invasive plate osteosynthesis (MIPO). First clinical results in different series [4, 5] seem to show definite biological advantages of minimally invasive approaches that appear to enhance fracture healing and reduce the risk of infection. MIPO procedures with submuscular plating have been shown to preserve peristomal blood supply when the internal fixator principle using locking head screws (LHS) is applied correctly (LISS and LCP system) (chapter 3.3.4) [6]. The short self-drilling and self-tapping LHS can be inserted through stab incisions using special protection sleeves.

2 Definition of minimally invasive osteosynthesis (MIO)

Minimally invasive osteosynthesis (MIO) includes all forms of fracture fixation that

- use small soft-tissue windows which allow insertion of implants or instruments;
- cause minimal additional trauma to the soft tissue and fracture fragments;
- use indirect (traction table, external fixator, distractors, manual traction), or gentle direct reduction techniques (K-wires, reduction screws, percutaneous reduction forceps, joysticks);
- can apply the biomechanical concepts of relative stability or, exceptionally, absolute stability [7].

By this definition, MIO includes all types of percutaneous fracture fixation such as external fixation, closed intramedullary nailing, percutaneous K-wire or screw fixation as well as minimally invasive plate osteosynthesis (MIPO). In this chapter MIPO is covered, while other minimally invasive techniques can be found elsewhere (intramedullary nailing (chapter 3.3.1), external fixator (chapter 3.3.3), internal fixator (chapter 3.3.4), percutaneous K-wire or screw fixation (chapter 3.2.1)).
3 Indications for minimally invasive plate osteosynthesis (MIPO)

The option for minimally invasive plate application must always be balanced against other possibilities, especially intramedullary nailing. Both have similar biological advantages over conventional ORIF and require careful preoperative planning.

MIPO is used
- in epi-/metaphyseal fractures;
- when soft-tissue conditions preclude an open procedure;
- when fracture pattern is not suitable for intramedullary nailing (intraarticular extension, narrow, deformed or obstructed medullary canal);
- when other implants have already been used (eg, arthroplasty);
- when still open growth plates are involved in a fracture;
- when an image intensifier is not available;
- when the patient’s general condition (eg, polytrauma, lung contusion) precludes additional systemic insult, eg, by medullary reaming.

Plate osteosynthesis must provide the correct biomechanical environment for a specific fracture pattern. For example, plating of a simple metaphyseal fracture should always be by interfragmentary compression providing absolute stability, which can often be combined with minimally invasive techniques. However, this principle should not be neglected in favor of smaller skin incisions.

4 Preoperative planning for MIPO

Preoperative planning is of paramount importance with MIPO techniques.

4.1 What does planning include?

Planning should consider all steps of the procedure and therefore include the appropriate approaches, reduction techniques, instruments, and implants. Before performing MIPO, several questions must be asked:
- Where are the anatomical danger zones?
- How can reduction be achieved and also maintained?
- Should the fixation provide relative stability by bridge plating, or absolute stability by interfragmentary compression?
- Are all the instruments and implants available?
- Is the C-arm available?
- Is there a need for additional instruments to facilitate percutaneous reduction?
- Is there a need for contouring of the plate?
- When is ORIF indicated if the original goal of MIPO cannot be achieved?

4.2 Danger zones

A thorough knowledge of surgical anatomy is necessary to avoid damaging vital structures, such as nerves and blood vessels.

It is essential to know the cross-sectional anatomy for the passage of pins and wires (eg, circular external fixator) as well as the course of vessels and nerves for submuscular insertion of plates and percutaneous insertion of screws.
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4.3 Reduction

Tools
Indirect reduction should generally be planned prior to implant application. Indirect reduction by traction can be performed manually, with a traction table, with distractors or external fixators, or directly by Schanz screws. Special instruments have been developed for direct reduction techniques such as manipulators applied to Schanz screws, or the colinear reduction forceps (Fig 3.1.3-1) (chapter 3.1.1).

Maintaining reduction
Once reduction has been obtained, it should be maintained temporarily for imaging and until the appropriate plate and screws have been inserted.

Fig 3.1.3-1a–d Colinear reduction forceps for minimally invasive percutaneous reduction of fractures used on a periprosthetic fracture of the femoral shaft.

a Reduction forceps with different tips for MIPO of shaft fractures (1), pelvic fractures (2), and articular fractures (3).

b Reduction forceps in situ.

c Fracture reduction with the colinear reduction forceps in a periprosthetic fracture.

d Application of the reduction forceps after reduction and percutaneous insertion of a plate.
3 Reduction, approaches, and fixation techniques

3.1 Reduction and approaches

4.4 Absolute or relative stability?

For most MIPO techniques relative stability is generally recommended. However, in simple metaphyseal type A fractures anatomical reduction and absolute stability with interfragmentary compression is recommended to reduce the strain in the gap and to permit direct fracture healing. Absolute stability is also mandatory for fractures involving the articular segment. However, in complex meta-/diaphyseal fractures, relative stability with a long bridging plate is usually adequate for the alignment and approximation of intermediate fragments.

4.5 Implants

Conventional plates (LC-DCP)

Conventional plates should be very long (10–14 holes in the tibia and humerus, 18–24 holes in the femur). A general rule is that the plate should be at least three times the length of the fracture zone, often reaching from one metaphysis to the other. Exact contouring of the plate, especially at either end, is required in order to prevent secondary displacements (angulation and rotation). A plastic bone model may help to contour the plate preoperatively.

Locking plates (LISS/LCP)

Thanks to the locking head screws (LHS) these implants, if used as internal fixators, do not require as precise contouring as conventional plates (Fig | Animation 3.1.3-2), because the implant is not pressed against the bone and there will be no loss of reduction. However, minimal contouring of one plate end may be advisable to prevent prominence of the plate under the skin (chapter 3.3.4).

- Contouring of the LCP should not occur within the threaded holes as deformation may reduce firm purchase of the locking head screw.

4.6 Alternative plan

There should always be an alternative plan in case MIPO cannot be carried out as desired. It should include:
- minimal opening of the fracture site to apply an instrument for direct reduction;
- exposing the fracture as in conventional plating;
- changing to intramedullary nailing or external fixation;
- asking for help from more experienced surgeons.

Fig | Animation 3.1.3-2a–b

a  With conventional screws the bone is reduced (pulled) towards the plate.
b  Angular stability of the locking head screws ensures maintenance of initial reduction even if the plate is not contoured exactly. This allows the LCP to be inserted by MIPO technique.
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A thorough knowledge of the different pros and cons of MIPO will help to reduce pitfalls associated with this kind of surgery such as malreduction, implant failure, malunion, delayed union, and nonunion [8].

4.7 Intraoperative imaging

The image intensifier is an essential piece of equipment for all MIO procedures. The view should be adequate (9- or 12-inch screen) to get as large a picture as possible for the assessment of axial alignment.

- The position of the C-arm is critical in order to achieve orthogonal views during surgery, and should be tested before scrubbing.

MIPO carries the risk of prolonged use of the image intensifier. For distal femoral fractures radiation time during surgery averaged 5.4 minutes in a multicenter study, including the learning curve [5]. Reduction tools like joysticks with T-handles or the large femoral distractor [7, 9] are helpful for reduction and maintaining reduction during radiological assessment and implant insertion. Computer navigation has the potential to further reduce exposure to radiation.

5 MIPO in specific bone segments

5.1 Humerus (chapter 6.2.1; 6.2.2)

MIPO has been used for fractures of the proximal humerus and humeral shaft. However, the axillary and radial nerves are situated close to the bone and may be at risk with these procedures. MIPO is currently being evaluated for the humerus and should only be applied by surgeons with expertise in MIPO techniques.

5.2 Femur

The whole length of the femur is amenable to MIPO on the lateral side. There is excellent soft-tissue coverage and no important neurovascular structure is located in this part of the surgical field. Screw insertion through stab incisions may be possible, but in obese or muscular patients a 2-4 cm incision at the end of the plate is recommended to ensure accurate positioning of the implant in relation to the bone.

5.2.1 Femur, proximal (chapter 6.6.1)

Percutaneous insertion of 7.3 mm cannulated lag screws is a common technique for the stabilization of minimally displaced subcapital fractures (31-B1). The sideplate of the dynamic hip screw can be inserted percutaneously for the treatment of intertrochanteric fractures (31-A). MIPO has also been described for the insertion of a 95° angled blade plate (Fig 3.1.3-3) or dynamic condylar screw (DCS) for the treatment of subtrochanteric fractures. The procedure requires some experience and is best tried out on a cadaveric specimen.

Fig 3.1.3-3 MIPO for a proximal femur and shaft fracture with a 95° angled blade plate.
3 Reduction, approaches, and fixation techniques
3.1 Reduction and approaches

5.2.2 Femur, shaft (chapter 6.6.2)

Most femoral shaft fractures are treated with an intramedullary nail. However, plate fixation may be considered in fractures that extend into the proximal or distal metaphysis, in adolescents with an open proximal growth plate, in polytrauma patients, or when an associated fracture precludes intramedullary nailing (e.g., acetabular or displaced femoral neck fracture). The long epiperiosteal elevator is very useful for creating a submuscular tunnel without stripping the periosteum. The plate can be introduced from either proximal or distal, depending upon the fracture pattern and preoperative plan (Fig 3.1.3-4).

5.2.3 Femur, distal (chapter 6.6.3)

Extraarticular distal femoral fractures are a good indication for MIPO with the LISS-DF or LISS-LCP as an alternative to the retrograde intramedullary nail. Displaced articular fractures require anatomical reduction, which in turn will usually necessitate ORIF of the joint block. However, the lateral plate can be inserted with MIPO techniques and through a submuscular tunnel (Fig 3.1.3-5).

5.3 Tibia

The entire length of the tibia is amenable to MIPO by a lateral as well as a medial approach. The medial aspect of the bone lies subcutaneously, which makes the insertion of plates technically easy. However, the absence of muscle cover means that the plate may compromise soft-tissue healing and the implant may be prominent underneath the skin. Laterally inserted plates will be covered by muscle, which makes them safer for soft-tissue healing, but they are more difficult to contour and apply. The major neurovascular structures are outside the surgical field with either approach, but the surgeon must be aware of the great saphenous vein and nerve medially, and the anterior tibial neurovascular bundle in the distal third of the tibia and the superficial fibular nerve laterally.
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5.3.1 Tibia, proximal (chapter 6.8.1)
Lateral tibial plateau fractures can be treated with a submuscularly inserted plate. Open reduction of the joint is usually necessary. Medial plateau fractures are treated in a similar manner. Bicondylar fractures with complex metaphyseal injuries often require two plates, and MIPO in these cases is very useful for the introduction of a posteromedial buttress plate. MIPO reduces the problems associated with double plating through a single incision. Arthroscopy may be used to confirm intraarticular reduction and to ensure that implants do not protrude into the joint.

5.3.2 Tibia, shaft (chapter 6.8.2)
Tibial shaft fractures extending either into the knee or ankle joint may require plate fixation. MIPO may be advantageous to reduce the exposure. Complex fractures will require a bridging technique, while simple fracture patterns require anatomical reduction and absolute stability if a plate is used. With careful planning and skilled application, this can be achieved by MIPO techniques (Fig 3.1.3-6).

5.3.3 Tibia, distal (chapter 6.8.3)
The following text describes an example of MIPO (Fig 3.1.3-7) in the distal tibia.

Case
The fracture pattern and its location in the distal metaphysis is an indication for MIO. An intramedullary nail was not considered because the distal interlocking screws would be lying in the fracture zone resulting in inadequate fixation of the distal fragment. Bridge plating was chosen due to the complex fracture pattern.

Approach
The surgical approach should always consider the possibility of switching to an open procedure if indirect reduction cannot be obtained and maintained. Therefore a slightly curved incision over the medial malleolus is recommended as it may be extended into a standard open approach to the distal tibia.

Dangers
The saphenous vein and nerve must be identified and gentle subcutaneous tunneling should be performed with an epiperiosteal elevator (Fig 3.1.3-8).

Options for reduction
Manual traction:
- Pros: It is easy to apply, and its flexibility allows maneuvers in any direction.
- Cons: Radiological assessment is not possible without exposing the surgeon’s hands to radiation.

Fig 3.1.3-6 MIPO using a LCP for complex distal tibial fracture. Open reduction of the joint surface was performed through a small anterolateral incision.
3 Reduction, approaches, and fixation techniques

3.1 Reduction and approaches

Fig 3.1.3-7a–f

a–b Closed distal tibial fracture 42-B1.3.
c–d A LCP bridge plating procedure was selected to obtain correct axial alignment for this complex fracture pattern. After plate insertion, as a first step, the two 4.5 mm lag screws were placed through the plate into the wedge fragment. Next two LHS were applied on either side. Note the clips at the level of the skin incisions, which indicate the extent of the incisions.
e–f X-ray after 1 year.

Fig 3.1.3-8a–c

a Epiperiosteal preparation of the plate bed. The great saphenous vein and nerve is protected (rubber sling) throughout the procedure.
b Insertion of the plate.
c Epiperiosteal elevators.
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External fixator (different frames, eg, tube-to-tube connection):
- Pros: Easy application and retention of reduction for radiological control and plate insertion.
- Cons: The larger the distance between the pins, the more difficult it is to obtain effective distraction and to reduce the fragments.

Large distractor, eg, joint bridging between tibia and calcaneus:
- Pros: This allows distraction when shortening is a problem (delayed case) and maintains reduction for x-ray control.
- Cons: Rotation is less easy to correct and joint bridging may result in a lot of strain on the joint capsule.

Reduction with the help of a plate:
- Pros: A precontoured plate is inserted subcutaneously and medially. Thanks to the intact and tight soft-tissue sleeve the plate tends to align the fracture and acts as a splint. When using a conventional LC-DCP exact plate contouring is mandatory to prevent any loss of reduction when the plate is fixed (pressed) against the bone (Fig 3.1.3-2). Furthermore, the order of screw insertion is essential and must be carefully planned. Loss of reduction is generally not a problem when a LCP with LHS is used, because the plate does not disturb the alignment when LHS are tightened.
- Cons: Reduction depends upon precise contouring of LC-DCP.

If the techniques of closed indirect reduction described above are not successful, additional maneuvers may be necessary, such as:

Reduction tools applied close to the fracture, eg. K-wires, Schanz screws, pushers, or even digital pressure:
- Pros: Direct force is applied where necessary.
- Cons: Additional soft-tissue incisions need to be made close to the fracture.

Percutaneous pointed reduction forceps (Fig 3.1.3-9):
- Pros: Direct reduction of the fracture is performed similar to an ORIF procedure, with near perfect results in simple fractures.
- Cons: Additional skin incisions close to the fracture focus are needed, which can further damage vascularity.

Percutaneous reduction screw (definition: Tab 3.2.1-1):
- Pros: In case of a bridging plate and relative stability a reduction screw helps to approximate a wide fracture gap or to bring a butterfly fragment closer to the main fragments without interfragmentary compression. Position screws can then be inserted through the plate or independently.
- Cons: There may be tenuous periosteal connections to butterfly fragments, which could be stripped as the rotating drill or screw engages the fragment.

These maneuvers can be improved by using special MIPO tools which are designed to minimize trauma to soft-tissues and bone.
3 Reduction, approaches, and fixation techniques
3.1 Reduction and approaches

Switching to limited ORIF
In case closed reduction has not been successful, a gentle open reduction through a small incision should be considered. This possibility must be included in the preoperative plan, especially when dealing with delayed surgery, and helps to avoid frustrating attempts with prolonged exposure to radiation and unnecessary soft-tissue damage around the fracture site.

Pitfalls
In simple fracture patterns pure bridge plating is not recommended since a delayed union may result if the fracture gap remains too wide (> 2 mm), or if the internal fixator is too stiff because all plate holes have been filled with screws. In both cases implant failure due to fatigue or stress concentration at the level of the fracture may result (Fig | Animation 3.1.3-10).

Malreduction, especially malrotation, may be hard to check with MIPO as the image intensifier gives only a limited view of the axis. Intraoperative comparison with the separately draped, uninjured leg helps to prevent this. The methods for assessing rotational malalignment are well documented in chapter 3.3.1.

Postoperative treatment
Postoperative treatment of fractures stabilized with MIPO follows the same principles as after conventional plating. Partial weight bearing (15–30 kg) is recommended for 6–10 weeks, depending on the fracture pattern, the stability of fixation, the compliance of the patient, and the appearance of visible fracture bridging callus. Full weight bearing may be encouraged when the x-ray and clinical signs of fracture healing show consolidation.

Fig 3.1.3-9a–c  Distal tibial shaft fracture treated with MIPO using a LCP. Anatomical reduction with a percutaneous forceps (a) and application of a lag screw (b); the LCP serves as a protection plate. Postoperative x-rays, AP and lateral (c).
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**Stress distribution**
![Stress distribution](image)

Fig | Animation 3.1.3-10a–b  Stress distribution. Influence of screw fixation on forces within the plate.

**Complications**

**Skin breakdown**
Skin breakdown and superficial infection may occur when too much tension has been applied during surgery with retractors, respectively for the closure of the incision with heavy sutures.

**Deep infection**
Compared to conventional open procedures, infection rates after MIO have been reported to be lower [4], even in cases of severe open fractures.

**Malunion**
The difficulty of assessing correct axial and rotational alignment by image intensification may result in more cases of malreduction than with ORIF (6–34%) [4, 5, 10–12].

Indirect reduction techniques need to be practiced, and percutaneous application of special instruments for reduction must be very gentle.

- When using an internal fixator with locking head screws, the fracture should be reduced and correctly aligned prior to plate application because the plate will not assist the reduction.

This change of concept from conventional to locked plating is probably the most common cause of mistakes in MIPO.

**Delayed union/nonunion**
Nonunion is uncommon following MIPO, provided the principles of internal fixation are followed. In high-velocity fractures, the necessity for secondary intervention (bone grafting) is between 2.5–7% [4, 5]. If there is minimal callus formation at 6–8 weeks, one must watch the situation carefully and proceed to bone grafting at an early stage in order to avoid implant failure.

**Implant failure**
Plate breakage after MIPO has been described in cases of delayed union (absence of callus formation) [5, 7, 8, 13]. This may be due to distraction, a fracture gap wider than 2 mm, high-energy impact with soft-tissue injury and devascularization of the bone fragments, or failure to achieve absolute stability in simple fracture patterns.
3 Reduction, approaches, and fixation techniques
3.1 Reduction and approaches

Loss of purchase after percutaneous insertion has been observed with the LISS, when very long plates were used and the correct placement of the proximal end of the plate relative to the bone was not checked. This may result in tangential screw placement (Fig 3.1.3-11), which may go unnoticed as the locking head screws always appear to have good purchase in the threaded hole.

7 Implant removal

Implant removal after MIO may be more difficult than implant insertion. As swelling subsides, incisions are often no longer in their original position relative to a screw. While special instruments and drill bits may be required to facilitate plate removal after MIPO, a direct approach should be taken to remove individual screws. This is of special relevance when using titanium locking head screws that may be firmly locked in the plate if they had not been inserted properly with the torque-limiting screw driver [14].

8 Conclusion

Knowledge of fracture fixation has evolved rapidly in recent years. Where possible, the aim of surgery is to achieve biological fixation through tissue-preserving approaches. While this idea has been rapidly adopted throughout the world, clear concepts of the principles and proper performing of techniques of minimally invasive osteosynthesis remain a problem among surgeons. This chapter has outlined the steps required to perform minimally invasive surgery/minimally invasive plate osteosynthesis with emphasis on a safe and logical approach.

9 Bibliography

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