Minimally Invasive Osteosynthesis and Minimally Invasive Plate Osteosynthesis (MIPO)

Theerachai Apivatthakakul, M.D.
Department of Orthopaedics Faculty of Medicine, Chiang Mai University, Muomg, Chiang Mai 50202, Thailand.

Siriraj Med J 2006; 58: 1235-1243
E-journal: http://www.sirirajmedj.com

In all surgical disciplines, the operative methods that are described as minimally invasive are those methods that effectively reduce any additional trauma caused by the approach and the surgical procedures. The term "minimally invasive surgery" is being increasingly used. The goals are minimization of all procedures from positioning, approach, operation with reduction, retention and intraoperative assessments through aftercare.

Minimally invasive osteosynthesis (MIO) should belong nowadays in the treatment concept of each orthopaedic surgeon. The tendency to minimize the invasivity of every operation is a logical development considering the goal of each surgeon to reduce the iatrogenic damage caused by the operation. The term "MIO" stands for these criteria: Fracture zone is not opened, the fracture hematoma is well preserved, reduction is done by indirect maneuver or percutaneously by joysticks, small approaches for the application of the implants and intraoperative assessment of the reduction by imaging (fluoroscopy, arthroscopy or computer assisted surgery). MIO is not a new concept in orthopaedic surgery. Closed intramedullary nailing, percutaneous fixation of fractures using screws and Kirschner wires had been performed with satisfactory results. External fixator for severe open fracture or closed fracture with soft tissue injury which applied percutaneously also fulfilled the minimally invasive concept.

The MIO has gained complete acceptance for the treatment of diaphyseal fractures. In the majority of cases, this procedure is combined with insertion of intramedullary implant. In case of metaphyseal with or without articular fracture, the use of minimally invasive techniques depends on the extent of articular involvement. As for articular fractures, their main goal is anatomic reconstruction which can be achieved by direct open reduction or closed indirect reduction depends on the severity of articular injury. The metaphyseal and diaphyseal area is usually treated by indirect reduction and internal fixation with plate and screw.

The traditional approach for plating had many problems compared to minimally invasive nailing and was condemned and later abandoned for certain type of fractures. The slow progress toward improved soft tissue handling is evidenced by the inappropriate way that plating techniques are taught. Inadequate mentioned of soft tissue handling, preservation, exercised on plastic bone model without soft tissue and the textbook with the pictures of plates applied to white devitalized bone were the example that lead to misunderstanding. In their historical review, Miclau T, et al.[1] demonstrate that plating techniques have continued to evolved based on the concern for blood supply to the fracture site and minimally invasive reduction technique.

Fig 1. Bridge plating of the femoral shaft.The fracture is fixed only proximal and distal,the fracture zone is left undisturbed.

The application of plates using minimally invasive surgical techniques has gained popularity in last decade in the fracture that can not be solved by the minimally

Fig 2. Minimally invasive percutaneous plate osteosynthesis (MIPPO), the plate is inserted percutaneously by separate incisions to fix the femoral shaft fracture.

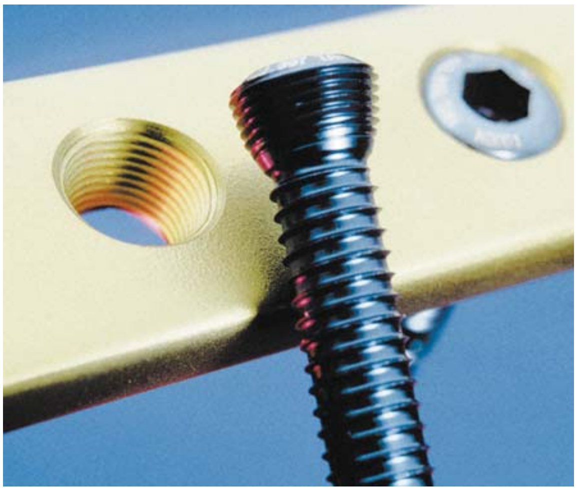

Fig 3. New plate with the locking head screw, a new concept of internal fixator that has the angular stability between the plate and screw head.

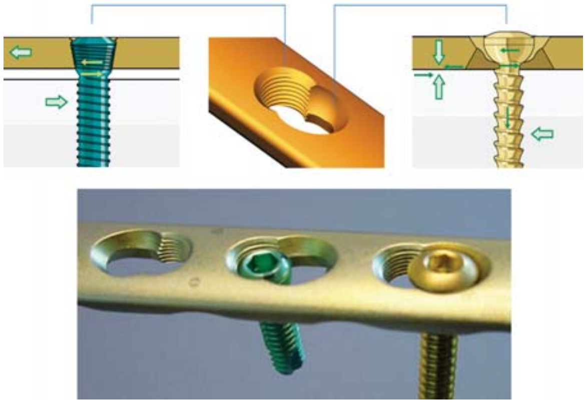

Fig 5. The LCP (Locking Compression Plate) combine the DCP and the locking head screw, the plate can be used as regular DCP or locking plate.

invasive nailing. [2-5] The history started with "bridge plating"[6] that mean this type of plate fixation technique required indirect reduction[7,8] only fixation of the proximal and distal fragment (Fig 1) that result in flexible fixation and avoids the need for precise reduction and application of too many implants and instruments, especially of the intermediate fragments, and took the advantage of indirect reduction to produce the best biological conditions for healing. The conventional plate was used first in the multifragmentary femoral fracture[9-12] by using the skin incision as long as the plate and preserved the vastus lateralis muscle at the fracture zone, bridging the fracture with plate and screw which produced great amount of callus formation. The next step was the question: "Why do we need such that long incision to fix the fracture?" The length of incision was reduced to two separate small incisions and a plate was inserted into the submuscular tunnel and the result was more satisfactory due to less bleeding and early rehabilitation.[3,5,13] This technique was firstly named "minimally invasive percutaneous plate osteosynthesis (MIPPO) (Fig 2). Experimental studies also have confirmed the superiority of minimally invasive plate osteosynthesis in the femur in preserving the integrity of the perforating as well as the nutrient arteries[14]. Many implants and instruments were designed to facilitate this surgical technique for example, the plate tunneling and insertion instruments. In the same period of time the invention of new plate with the locking head screw is introduced as a new concept of internal fixator that has the angular stability between the plate and screw head (Fig 3). By combining the two concepts of percutaneous plate insertion and internal fixator, the introduction the LISS (Less Invasive Stabilization System) which was designed for application in the metaphyseal and epiphyseal areas the distal femur (Fig 4).[15] LISS could be considered the first plate that was specifically designed and instrumented for application using a minimally invasive sub-muscular approach as it has its own insertion handle which facilitated the introduction of the implant submuscularly and at the same time acts as a drill guide for accurate insertion of the screws through separate small stab wounds.

LCP (Locking Compression Plate) was the latest series of internal fixators (Fig 5) to be introduced and has the unique feature of being able to be used as a standard dynamic compression plate or as an internal fixator due to the ingenious design of a special combination plate hole.[16] LCP can be used for diaphyseal fractures and when applied in the internal fixator mode, offers an advantage of maintenance of primary reduction of the fracture while avoiding any secondary loss of reduction under load. This feature makes the LCP suitable for minimally invasive

Fig 4. The LISS (Less Invasive Stabilization System) which is designed for percutaneous insertion and aiming arm for the locking screw.

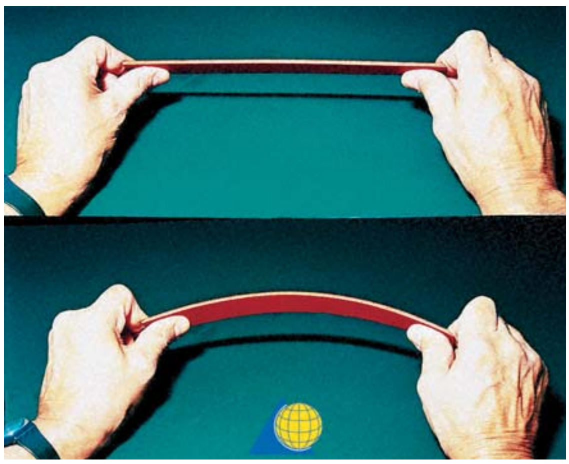

Fig 6a. The fixation only on either end of the plate will distribute the stresses over a long segment of the plate, the stress per unit area is low which reduce the risk of plate failure.

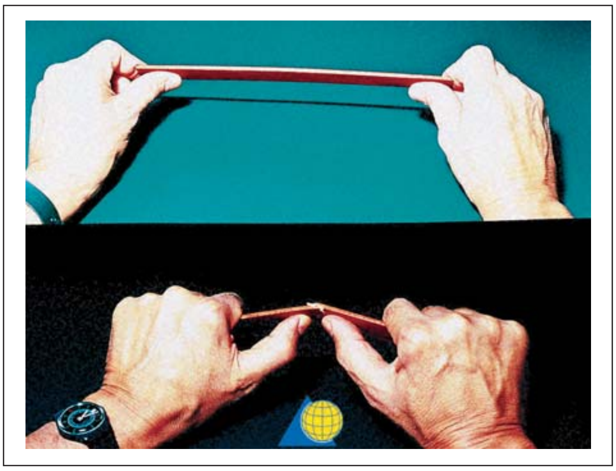

Fig 6b. In short fracture the bending stresses will be concentrated and centered on a short segment of the plate.

application as it does away with the need for accurate contouring of the plate to the bone.

Biomechanic principle of bridge plate

Usually, most of the fracture types treated by bridge plate principle are multifragmentary fractures. The technique has brought a basic change into the fracture treatment. Rather than relying upon absolute rigid fixation through compression of the fracture, this technique maintains the alignment by bridging the fracture without compressing or splinting the fracture. Splinting consists of a connection of an implant to the broken bone. The stability of this composite system depends on the stiffness of the splint and the quality of the anchorage of the splint to the bone.[17] The technique can either be achieved by traditional implant or locking plate.

-Stress distribution on the plate

Long plate bridging the comminuted fracture zone with fixation only on either end of the plate will distribute the stresses over a long segment of the plate; the stress per unit area is low which reduces the risk of plate failure (Fig 6a). In short fracture the bending stresses will be concentrated and centered on a short segment of the plate which will break more easily due to fatigue (Fig 6b).

Relatively long plates should be used while stress concentration within the plate should be avoided by placing the screws one or two plate holes away from the fracture zone and spacing out the rest of the screws within the plate.

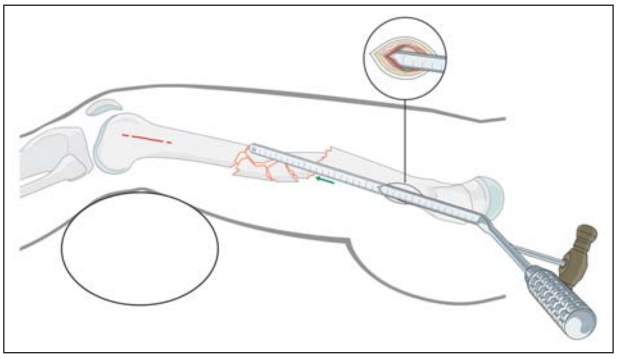

Fig 7. The pull out resistance of the screw can be improved by diverging the screw.

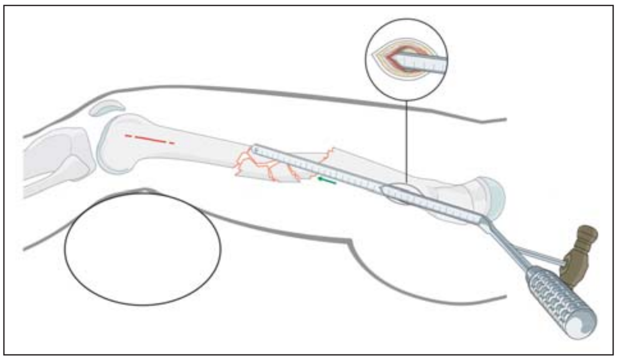

Fig 8. The submuscular tunnel is then prepared with the tunneling instrument over the periosteum.

-Length of the plate

The appropriate length of the plate is one of the most important steps in using plates. It depends on the fracture pattern and the mechanical concept used for fixation. In the past, a short plate was often chosen to avoid a long skin incision and extensive soft tissue dissection. With the newer techniques of MIPO, the plate length can be increased without additional soft tissue dissection. From the mechanical point of view, we should keep the plate loading and the screw loading as low as possible to avoid fatigue failure due to cyclic loading. The plate length is usually at least three times longer than the overall comminuted fracture zone and 8-10 times for simple fracture.[17]

-Number of screws

The previous AO/ASIF guidelines for a specific number of the screws or cortices in each fragment should no longer be used. It much more important to insert few screws but these screws should be distanced apart that causes no need to fill up every hole of the plate with a screw. Usually, three well-spaced normal screws on each

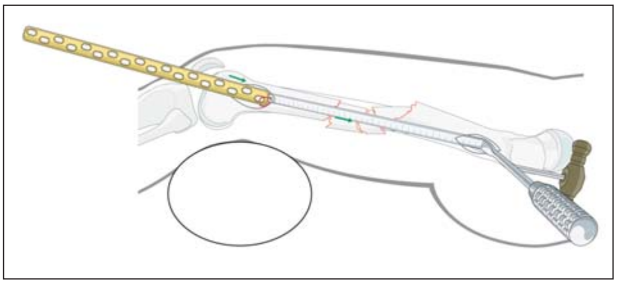

Fig 9a. One end of the plate is tied with a suture to the end of the tunneler.

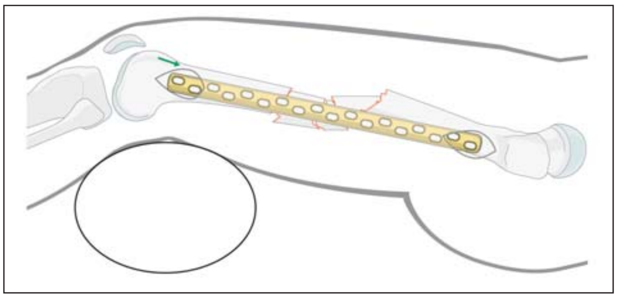

Fig 9b. As the tunneler is withdrawn, the plate is pulled into position. Adapt from: G On Tong, Suthorn Bavonratanavech (2006) AO Manual of Fracture Management - Minimally Invasive Plate Osteosynthesis (MIPO), Stuttgart New York: Georg Thieme Verlag.

Fig 10. The plate holder fixed to one end of the plate is used as the tunneler and insertion handle.

side of the fracture will provide adequate stability for fracture healing by callus. With the locking head screw two monocortical screws are the minimal requirement to keep the construct stable in the normal bone quality. However, for safety reason, the author recommends the use of more than two screws per fragment.

-Screw direction

Parallel screw insertion has less pull-out resistance, when apply a pull-out force the screw will fail one after the other. The pull-out resistance of the screw can be improved by diverging the screw (Fig 7).

Indications for MIPO

Upper extremity

Multifragmentary fracture of the humerus.

Lower extremity

Metaphyseal - diaphyseal fracture that cannot be treated with intramedullary nail or nailing has technical difficulty, for example, ipsilateral femoral neck and shaft fracture, diaphyseal fracture with small or deformed medullary canal, fracture with open growth plate, proximal and distal fracture of the tibia that tend to have angular deformity after nail insertion.

Surgical techniques

Preoperative planning

The preoperative plan should also include the number, type, location and order of insertion of the screws. Contouring of the plate, if necessary, is carried out preoperatively. If the conventional plate is to function as a compression plate for simple fractures, accurate contouring

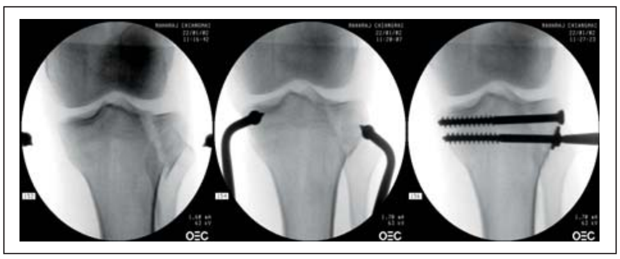

Fig 11. A large pelvic reduction clamp can be used, especially in simple articular fracture with metaphyseal extension.

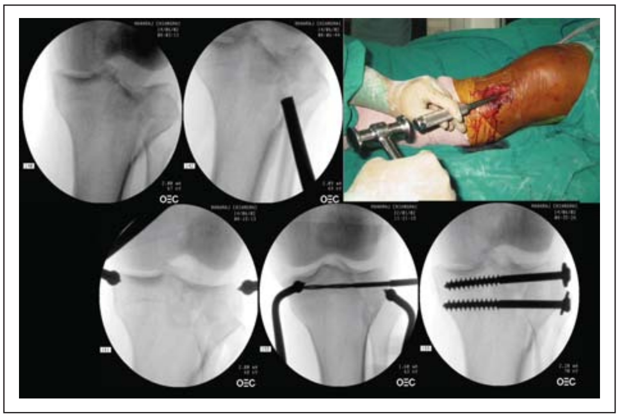

Fig 12. The depress articular fragment can be reduced through the lateral window with impactor and fixation with the percutaneous screw.

with pre-bending is mandatory in order to avoid the loss of primary reduction.

Position and approach

The patient is supine on the radiolucent table which enables intraoperative assessment of the limb alignment. The fracture table can maintain the length and the rotation of the fracture but intraoperative assessment of the limb alignment is difficult or not possible.

Skin incisions are made, corresponding in position to both ends of the plate.

Tunneling

Two separate incisions on each fragment of the bone are performed and deep dissection to the bone without stripping of the periosteal. The submuscular tunnel is then prepared with the tunneling instrument over the periosteum (Fig 8) except in the MIPO of the medial surface of the tibia that the subcutaneous tunnel is prepared over the periosteum.

Plate insertion

Plate insertion can be done in several ways. If a tunneler is used, one end of the plate is tied with a suture to the end of the tunneler (Fig 9a) as the tunneler is withdrawn, the plate is pulled into position (Fig 9b). Another way is to fix one end of the plate with a plate holder (Fig 10) which is then used to guide the plate into position along the track created by the tunneler.

Reduction techniques

Once the plate is in place, screw insertion can follow. Usually, one screw is first inserted into an end of the

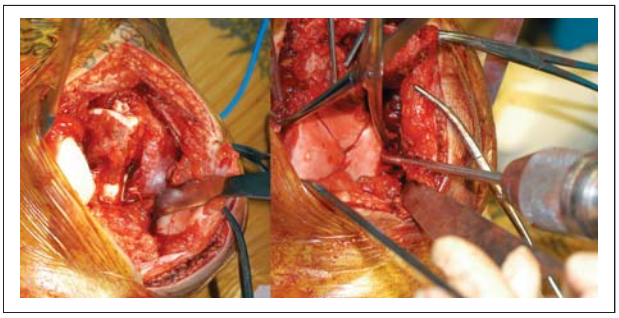

Fig 13. Insertion of schanz screw in extra articular part of each condyle as a manipulator or joystick.

Fig 14. The bolster inserts under the knee to relax the muscle pull of the gastrocnemius muscle.

plate, the other end of the plate should be temporarily stabilized with a K-wire, a conventional screw after initial reduction is done to prevent the plate from shortening and rotation. Preferably, the proximal end of the plate is fixed first as it is easier to control the position of the distal fragment by traction and manipulation. The quality of fracture reduction is checked. If it is satisfactory, the rest of the screws are inserted according to the preoperative plan. Usually, three screws on each side of the fracture would provide adequate stability. The screws should be spaced out and inserted obliquely in a divergent manner to obtain a better hold in the bone.

The reduction technique is one of the most difficult steps to perform the MIPO. In general, a modern orthopaedic surgeon should be familiar with the different reduction techniques, ranging from direct and open manipulation to indirect closed reduction. The decision should be made at the time of preoperative planning.

There are many techniques that can achieve the desire reduction but the key is how to minimize the negative effect. A surgeon has to learn and master these techniques according to the concept of biological fixation particular with minimally invasive.

Goal of reduction

It is well accepted that fracture reduction is a crucial factor in achieving bony union and preserving form and function. The degree of accuracy of reduction can, however, range from axial realignment to anatomical reduction of each fracture fragment. Not every type of fracture requires anatomical reduction, the surgeon has therefore to select the appropriate degree of accuracy and the proper technique. The key is to use the method of reduction with the least damage of soft tissue and blood supply at the fracture area.[7]

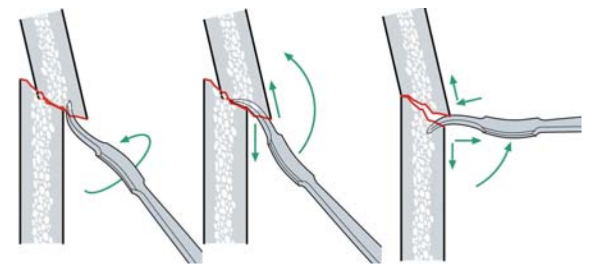

Fig 15. Small hohman retractor inserts between the fracture as a lever is helpful for reduction.

Fig 16. A large pelvic reduction clamp can be used for reduction, especially in fractures around the knee.

-Intraarticular fractures

It has been shown that anatomical reduction and stable fracture fixation must be achieved in order to have good healing of the articular cartilage. Precise reduction is of crucial importance to avoid local overload and exposure of subchondral bone, thus reducing the incidence of post-traumatic arthrosis. After achieving stable fixation with interfragmentary compression, early range of motion exercise can be started.

-Multifragmentary diaphyseal fractures

It is only essential to achieve restoration of the length, mechanical axis, and rotational alignment of the main fracture segments that carry the joint surfaces. It is unnecessary to achieve precise reduction of each fracture fragment to have a nice looking X-ray.

-Simple diaphyseal fractures

In transverse, oblique and spiral, it is favourable to achieve anatomical reduction. Absolute stability with compression is recommended as a method of fixation.

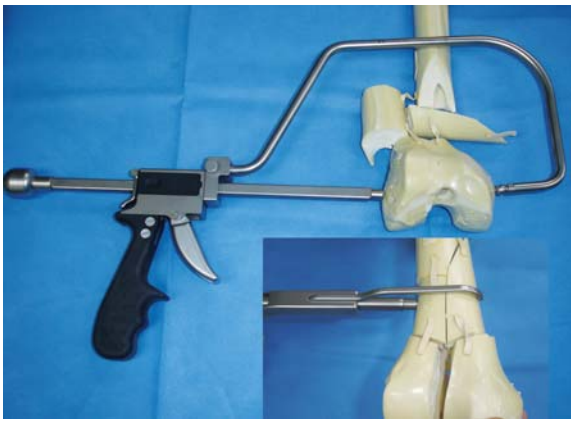

Fig 17. Collinear reduction forceps with different arms for periarticular and shaft reduction in minimally invasive surgery.

Fig 18. Cerclage wiring can be helpful in reducing a large wedge fragment in an oblique or spiral fracture.

Method of reduction

-Direct reduction

In general for direct reduction a fracture is exposed, the fracture fragments can be manipulated directly. All maneuvers are seen and controlled under direct vision at the fracture area. This kind of reduction technique is easier than indirect reduction and the reduction can be more precise. However, the application of reduction forceps often damages the soft tissue surrounding the bone, thus affecting the vascularity of bone fragments.

Indications for direct reduction

-Simple diaphyseal fractures are often treated with anatomical reduction and rigid internal fixation. It is technically straightforward and the result is easy to control. The aim of treatment is absolute stability that will result in direct bone healing. In order to achieve this, the fracture site often needs to be exposed but as minimal as necessary.

-Articular fracture, the success of surgery will rely on restoration of the articular surface. A small direct incision over a specific articular fragment to achieve reduction should be used. Pre-op CT scan is necessary to locate the appropriate approach and reduce the exposed area for reduction of the articular fracture.

Indirect reduction

As for indirect reduction, the fracture site is not exposed and remains covered by the surrounding soft tissues. Hence, there is maximal preservation of the biology surrounding the bone fragments. Reduction is accomplished using instruments or implants introduced away from the fracture zone, or through minimal incisions. To achieve reduction, traction is normally applied in the long axis of the limb. This works only when the fragments are still connected to some soft tissues. However, since there is no direct visualization of the fracture site, the reduction will not be as anatomical. In most cases, there will be gaps between the fracture fragments and healing across the fracture gaps will be achieved by callus formation.

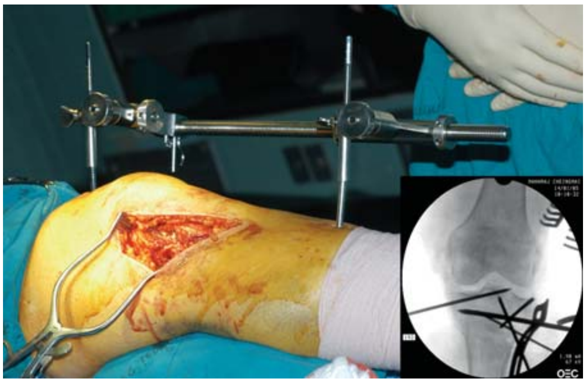

Fig 20. Distractors is useful to distract the joint for reconstruction of depressed articular fracture of tibial plateau.

Indication for indirect reduction

-Multifragmentary diaphyseal fracture which is vulnerable to soft tissue stripping during reduction.

-Metaphyseal diaphyseal fracture that needs only the correct limb alignment.

Techniques for reduction

Technique for reduction of articular fractures

Different technique can be use depending on the pathoanatomy of the articular fracture.

-Manual traction with percutaneous technique

Closed indirect reduction can be achieved with manual traction. This forms the basis of ligamentotaxis. However, this only works when the fragments are still connected to soft tissues, e.g., ligaments and capsule. In simple wedge fracture from articular surface extended to metaphyseal area without depress articular surface. The exact reduction of the spike of metaphyseal fragment will gain the anatomical reduction of the articular surface without exposure of the joint. The reduction can be done by a small incision

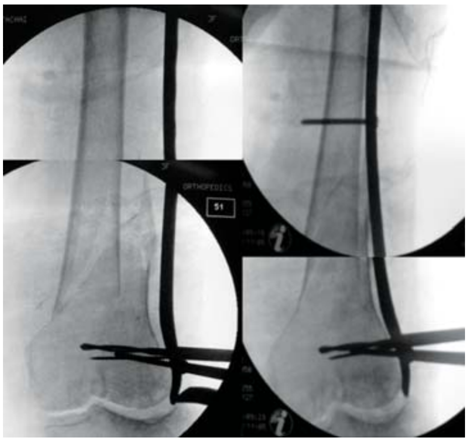

Fig 19. A compression screw draw the metaphyseal fragment to the anatomically shaped implant.

Fig 21. The manipulator with sharp tooth catches on the bone to prevent rotation connect with the clamp uses for reduction and temporary fixation of the femoral shaft fracture.

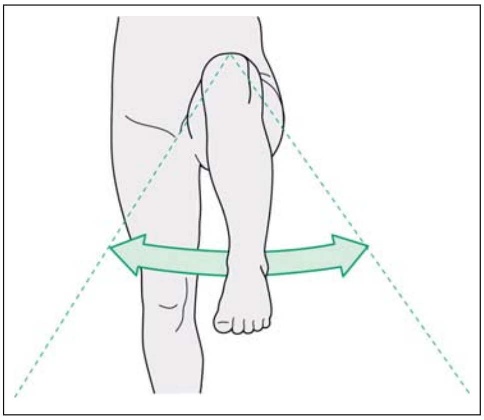

Fig 22. The rotation of the femur can be checked by the hip rotation test. Measurement with the patient lying on his back; hip and knee both flexed at 90 degree.

Fig 24. The tibial alignment grid for intraoperative evaluation for the coronal plane malalignment of the tibia.

or percutaneous and maintained by K wire or a large pelvic reduction follow by percutaneous lag screw fixation (Fig 11).

-Closed technique with arthroscope or Image intensifier

In more comminuted articular fractures, or pure depression some loose articular fragments are often present. If the fragments are of considerable size, they are amenable to reduction under fluoroscopic guidance, without exposing the fracture site. In depressed articular fractures, one can only assess the reduction of the articular surface with direct inspection. While conventional arthrotomy can be used to achieve this, arthroscopy has gained popularity as an adjunct to assess fracture reduction, especially in the wrist and the knee.

Impacted articular fragments must be elevated and reduced. This can usually be achieved by working through the fracture line or through a window created in the metaphyseal cortex. The image intensifier can help a surgeon to locate the depressed fragment and to assess the accuracy of reduction (Fig 12). Once the reduction is satisfactory, one should perform a fixation of the intraarticular component of the fracture. Depending on the site and the size of the metaphyseal defect, one can decide on the need for additional cancellous bone grafting or artificial bone substitute.

-Open reduction with direct manipulation

In case of severely displaced articular fracture, open reduction is still necessary to achieve anatomical reduction. For example, in intercondylar fracture of distal femur flexion of the knee with the support underneath will relax the pull of gastrocnemius muscle. Insertion of a Schanz screw in extra articular part of each condyle as a manipulator (Fig 13) will facilitate the reduction of

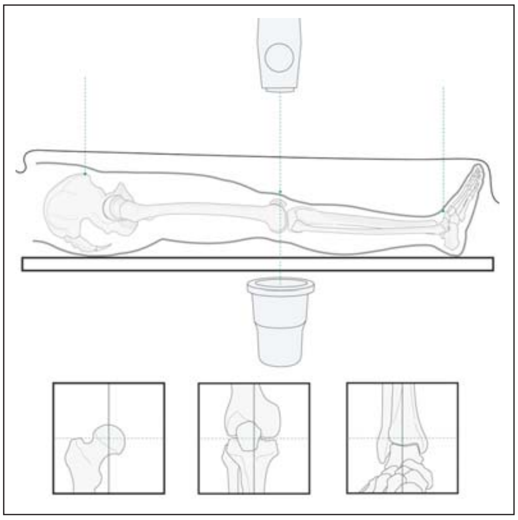

Fig 23. Cautery cable technique using image intensifier for checking alignment in the frontal plane: The knee is fully extended and the patella must face anteriorly.Use the image intensifier to marking the center of the hip joint and ankle joint. An assistant now spans the cautery cable between these two surface markings.When the knee joint is viewed with the image intensifier, the cable should run centrally.

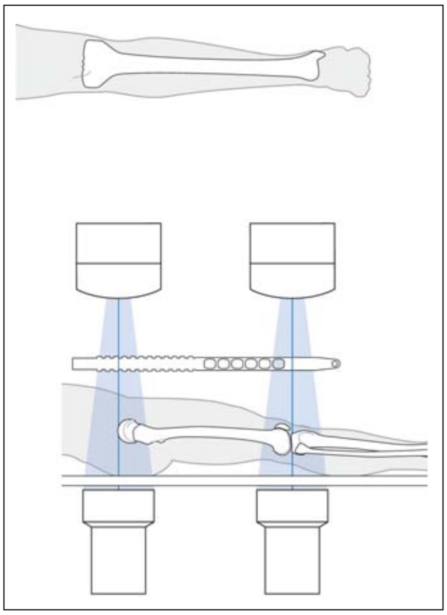

Fig 25. "Meterstick technique" the metal ruler uses for intraoperative evaluation of the limb length by comparing to the uninjured side.

articular surface without excessive exposure of the medial condyle. In order to assess the quality of reduction full flexion of the knee is necessary.

Technique for Reduction of diaphyseal fractures

The fracture fragments are not visualized. The unexposed fracture site still presents great difficulty in the reduction of the fracture.

-Traction

Traction can be done manually to obtain the axial alignment of the limb. A traction table may be useful to maintain the reduction in case that closed reduction is possible such as in femoral neck or intertrochanteric fracture. Radiolucent operating table should be the operating table of choice as there is a greater flexibility of manipulation in order to reduce the fracture. Moreover, the importance of imaging during surgery has become crucial. Most surgeons will rely on fluoroscopy in assessing the reduction and subsequent fixation.

-Supporting pads

The muscle forces acting on the fracture fragments often determine the pattern of displacement of a fracture. Traction alone can restore the normal length of the bone but will often exaggerate the axial malalignment instead of correcting it. A supporting pad or bolster can be used to correct the saggital plane deformity. It is often useful in periarticular fractures, particularly distal radius and distal femur (Fig 14).

-Small Hohman retractor

In transverse and short oblique fracture small Hohman retractor insert between the fracture as a lever is quite helpful for reduction (Fig 15).

-Reduction forceps

A large pelvic reduction clamp can be used, especially in fractures around the knee and ankle (Fig 16). Collinear reduction forceps with different arms for shaft and periarticular used in minimally invasive surgery have been devised and will increase the ease of fracture reduction with minimal exposure to fracture (Fig 17).

-Cerclage wire

Cerclage wiring can be helpful in reducing a large wedge fragment in an oblique and spiral fracture that is severely displaced (Fig 18) and may cause delay in bone healing.

-Reduction by implant

Anatomically shaped implants are useful in providing a guide to the reduction. The metaphyseal fragment is fixed to the plate first. One can use a normal compression screw to draw the metaphyseal fragment to the anatomically shaped implant (Fig 19).

-External fixator and distractors

These are the most common techniques to reduce and maintain the multifragmenatry fracture of diaphysis. A Schanz screw is inserted in each fragment away from the fracture zone and will not be obstructed for further surgical procedure. Manipulation of fracture site under image intensifier until satisfactory reduction is obtained and reduction is maintained by tightening the clamp and rod. Distractors are useful to distract the joint for reconstruction of depressed articular fracture such as tibial plateau (Fig 20) and pilon fracture.

-Manipulators or joystick

A Schanz screw can be inserted percutaneously in the articular or large bony fragments to facilitate the reduction. In case of diaphyseal fracture, a manipulator can be connected with a clamp of tubular external fixator to maintain the reduction (Fig 21).

Intraoperative assessment of limb alignment

Since the fracture is not directly visualized, the intraoperative assessment of limb alignment must be checked by using image intensifier or clinical assessment. This is one of the most important steps in fracture that has been done with indirect reduction technique.

-Rotational control

There are several methods for intra-operative assessment of the rotation of the femoral fractures both clinical and with radiographs. When the patient is operated on the radiolucent operating table, the rotation of the femur can be checked by "Hip rotation test". (Fig 22) This technique is easily performed and it is radiation-independent. However, the clinical judgment can be wrong, and it is also dependent on the pelvic ring position. Tibial rotation can be determined clinically compared to uninjured limb. Clinical assessment of the tibial rotation can be done by flexion of the hip and knee to 90^{o} with the ankle dorsiflexed, the internal and external rotation of the tibia at the knee is measured and compared with the uninjured limb.

-Frontal plane malalignment

Intraoperative technique for controlling frontal plane mal-alignment of the lower extremity by the "cable technique" 18 is a reliable method (Fig 23). Varus or valgus malalignment of the tibia can be evaluated by using a tibial alignment grid. 19 This is the instrument using multiple parallel K-wires mounted between two plastic plates with the distance of 1-2 inch extending from the knee to ankle joint and placed under the tibia. The AP view of the knee with the K-wire parallel to the knee joint is taken with the image intensifier. Move the C-arm distally to the ankle joint and an AP view of the ankle is taken, if the K-wire is parallel to the ankle joint it means that the knee joint and ankle joint are parallel (Fig 24).

-Limb length discrepancy (LLD)

LLD occurs more often in the femur than the tibia. The femur has bulky strong, muscles and it is more difficult to evaluate the length by clinical assessment than in the tibia. Most of the LLD is shortening while distraction of the fracture is rarely seen. The limb length can be assessed with or without image intensifier. The simple technique of using the cautery cord to measure the length of the femur from anterior superior iliac spine to the upper pole of the patella and measuring the length of the tibia from tibial tubercle to tip of medial malleolus can be accepted. However, with the swelling of the thigh or the knee, more error may occur. The length can also be assessed by an image intensifier using "meterstick technique" (Fig 25).

Postoperative Treatment

Postoperative regiment includes continuous passive motion for articular fracture. Since the mechanic of the bridge plate is flexible implant with less stress concentration to the plate, partial weight bearing began with 15-20 kilograms in the first week as same as conventional technique. The patient is advanced to full weight bearing based on the appearance of callus on follow-up radiographs that is usually seen earlier than in conventional techniques.

Complications

The aims of the MIPO technique are preservation of blood supply at the fracture site and minimizing soft tissue injury to avoid the complications that occur in conventional plating e.g., delayed union, non-union, infection or implant failure. However, with the indirect reduction technique the fracture zone is not directly visualized, so the correct limb length, rotation and frontal as well as capital alignment have to be carefully checked or measured pre-operatively or intra-operatively. Various techniques have been used to determine the limb length and alignment including CT, orthoradiography or teleradiography. However, these techniques are not available in the operation room. Most of the complications that occur in the MIPO technique are mal-alignment, either malrotation or angulation, and limb length discrepancy. Mal-alignments and limb length discrepancy of the upper extremity are much better tolerated than the weight bearing lower extremity. The MIPO technique has less delayed union or non-union compared to conventional plating and has less secondary surgical procedures, e.g., bone grafting. Gross mal-alignment or angulations with large gap sometimes lead to non-union or delayed union. When a limb mal-alignment occurs, it is advisable to correct it as early as possible. Delayed correction becomes more difficult, invasive, time-consuming and technically demanding.

Most complications occur from technical errors that are preventable, the surgeon has to be careful in every step of the surgery.

CONCLUSION

Although minimally invasive plate osteosynthesis is a relatively new concept in fracture treatment,the technique appears to have positive influence on functional outcome in most patients. Reduction of the surgical approach means less postoperative pain for the patient, earlier mobilization and shortening of hospital stay and the whole process of rehabilitation. This technique will certainly continue to improve the future osteosynthesis field. However, problems of intraoperative control of axis, and rotation in long bone fractures as well as the surgeon's high exposure to radiation remain unsolved in minimally invasive fracture surgery. Better instruments and implants will be developed and with ongoing research and clinical trials. New technologies as improved imaging, intraoperative navigation and percutaneous reduction tools will help to further reduce the invasivity of fracture surgery in the future and it has the potential of becoming one of the mainstays of fracture management in the years to come.

REFERENCES

1. Miclau T, Martin RE. The evolution of modern plate osteosynthesis. Injury 1997; 28(Suppl 1): 3-6.
2. Helfet DL, Shonnard PY, Levine D, Borrelli J Jr. Minimally invasive plate osteosynthesis of distal fractures of the tibia. Injury 1999; 28 (Suppl 1): A42-7; discussion A47-8.
3. Krettek C, Schandelmaier P, Miclau T, Tscherne H. Minimally invasive percutaneous plate osteosynthesis (MIPPO) using the DCS in proximal and distal femoral fractures. Injury 1997; 28(Suppl 1): 20-30.
4. Oh CW, Kyung HS, Park IH, Kim PT, Ihn JC. Distal tibia metaphyseal fractures treated by percutaneous plate osteosynthesis. Clin Orthop 2003; 408: 286-91.
5. Wenda K, Runkel M, Degreif J, Rudig L. Minimally invasive plate fixation in femoral shaft fractures. Injury 1997; 28(Suppl 1): 13-9.
6. Heitemeyer V, Kemper F, Hierholzer G. Severely comminuted femoral fractures treatment by bridging - plate osteosynthesis. Arch Orthop Trauma Surg 1987; 106: 327-30.
7. Mast J, Jakob R, Ganz R. Planning and reduction technique in fracture surgery. New York, Springer-Verlag, 1989.
8. Ostrum RF, Gee C. Indirect reduction and internal fixation. J Orthop Trauma 1995; 9: 278-84.
9. Bolhofner BR, Carmen B, Clifford P. The results of open reduction and internal fixation of distal femur fractures using a biologic (indirect) reduction technique. J Orthop Trauma 1996; 10: 372-77.
10. Siebenrock KA, Muller U, Ganz R. Indirect reduction with a condylar blade plate for osteosynthesis of subtrochanteric femoral fractures. Injury 1998; 29(Suppl 3): 7-15.
11. Kinast C, Bolhofner BR, Mast JW, Ganz R. Subtrochanteric fractures of the femur. Results of treatment with the 95o condylar blade plate. Clin Orthop 1989; 238: 122-30.
12. Baumgaertel F, Gotzen L. The biological plate osteosynthesis in multifragment fractures of the para-articular femur. A prospective study. Unfallchirurg 1994; 97: 72-84.
13. Apivatthakakul T, Arpornchayanon O, Chiewchantanakit S. Minimally invasive plate osteosynthesis (MIPO) of proximal and distal femoral fractures: Result of 20 cases. J Thai Orthop 2000; 25: 18-23.
14. Farouk O, Krettek C, Miclau T, Schandelmaier P, Guy P, Tscherne H. Minimally invasive plate osteosynthesis: does percutaneous plating disrupt femoral blood supply less than the traditional technique? J Orthop Trauma 1999; 13: 401-6.
15. Frigg R, Appenzeller A, Christensen R, Frenk A, Gilbert S, Schavan R, et al. The development of the distal femur Less Invasive Stabilization System (LISS). Injury 2001; 32(Suppl 3): SC24-31.
16. Frigg R. Locking Compression Plate (LCP): an osteosynthesis plate based on the dynamic compression plate and Point Contact Fixator (PC - Fix). Injury 2001; 32(Suppl 2): 63-6.
17. Gautier E, Sommer C. Guidelines for the clinical application of the LCP. Injury 2003; 34(Suppl 2): 63-76.
18. Krettek C, Miclau T, Grun O, Schandelmaier P. Intraoperative control of axes, rotation and length in femoral and tibial fractures. Injury 1998; 29 (Suppl 3): 29-39.
19. Apivatthakakul T, Patumasutra S. Tibial alignment grid for intraoperative evaluation of varus - valgus malalignment. J Thai Orthop 2000: 36-8.