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Minimally Invasive Plate Osteosynthesis (MIPO) in Long Bone Fractures – Biomechanics – Design – Clinical Results

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1. Introduction

Complex periarticular fractures of the long bones are difficult to treat. Classic intramedullary osteosynthesis do not provide a stable fixation (Wiss et al., 1986), while open reduction and rigid fixation by classic plates (recommended in the 60s-70s) is requiring large incisions with important deperiostation. Potential complications as infections, consolidation delays and construct damage due to nonunions undergo frequently (Bucholz et al., 1996). At that time, standard operative procedures considered that in epiphyseal-metaphyseal fractures, each fragment either from the articular or metaphyseal area should be subject for anatomical reduction and stabilization. There were obtained superior biomechanical results (absolute stability) but poor long-term biological effects (Baumgaertel et al., 1998). The main disadvantages of the anatomic reduction and rigid fixation by plates led to the development of the "biological plate osteosynthesis" concept. By the development of new plates (bridging plates, Limited Contact-Dynamic Compression Plate / LC-DCP, Point-Contact fixator / PC-Fix, plates with angular stability) and new surgical techniques (indirect reduction and Minimally Invasive Plate Osteosynthesis / MIPO), biological plate osteosynthesis is important to preserve bone vascularization, to improve consolidation, to decrease infection rate, to avoid iterative fractures or bone grafting. While indirect reduction techniques (using a distractor) are limiting the medial dissection and avoid bone grafting, MIPO techniques are limiting both the medial and lateral dissection in complex extraarticular fractures of the proximal and distal femur (Krettek et al, 1997a). MIPO techniques avoid direct exposure of the fracture site and transforms the implants in an internal extramedullary splint. Furthermore, MIPO was successfully extended to complex tibial fractures, being actually indicated in all long bones complex fractures that are not suitable for intramedullary osteosynthesis.

MIPO can be structured in 4 steps or techniques:

- a. MIPO technique with proximal and distal incisions. It was described by Wenda (Wenda et al., 1997) that have used a femoral limited lateral approach, proximally and distally from the fracture site, with plate insertion beneath the vastus lateralis;

- b. Minimally Invasive Percutaneous Plate Osteosynthesis (MIPPO) procedure was developed for extraarticular fractures of the distal and proximal femur; the key for this technique is represented by the usage of a two-part implant, the Dynamic Condylar Screw (DCS) (Krettek et al, 1997a);
- c. Transarticular Approach and Retrograde Plate Osteosynthesis (TARPO) procedure was developed by Krettek (Krettek et al, 1997b), for the osteosynthesis of the distal femoral intraarticular fractures.
- d. Procedures that uses specific implants for MIPO procedures (Plates with angular stability and tools for percutaneous insertion).

MIPO special characteristics are represented by:

1. The treatment purpose in minimally invasive plate osteosynthesis consists in anatomic reconstruction of the articular area, axis, rotation and length reestablishment for the metaphyseal-diaphyseal area, long plates osteosynthesis with screws fixed only distally and proximally from the fracture, bridging the comminution and with early functional rehabilitation.
2. Various studies results demonstrate that MIPO and TARPO have undeniable advantages over classic techniques: fast healing, reduced complication rate, reduced primary or secondary grafting requirements, and shortening of the operative time. Moreover, TARPO procedure provides a good exposure of the knee joint.
3. Good results obtained by minimally invasive plate osteosynthesis are due to a fast healing by vascularization protection and also to an increased resilience to mechanical stress.
4. Fixation with long plates only distally and proximally from the fracture site maintains a certain instability degree that is useful for an accurate and fast healing (relative instability).
5. Minimally invasive plate osteosynthesis is a demanding technique, requiring a cautious intraoperative clinical and fluoroscopic control in order to reestablish limb axis, rotation and length.

2. MIPO techniques in complex humeral shaft fractures

The treatment of complex humeral shaft fractures is a challenge due to the fact that open reduction and internal fixation with plates by anterolateral or posterior approach (the gold standard) is associated with a high morbidity (Livani et al., 2004; Sirbu et al., 2008) while locked intramedullary nails (the best option) do not offer a sufficient control of rotational movements in unstable and distal fractures (Rommens et al., 2000; Changulani et al., 2006; Sirbu et al., 2008).

In a recent study on plastic bones (Asaftei et al., 2010) we have evaluated the mechanical behavior of three different types of implants used in the osteosynthesis of comminuted humeral shaft fractures. We instrumented the fractures with 3 types of implants: an intramedullary nail, two types of locked plates and a "classic" DCP. All of them were submitted to torsion essays in external and internal rotation as to obtain the same amount of torque. The loading-deforming diagrams were compared and statistically analyzed for each type of implant.

The shorter locked compression plate (LCP- Synthes®) seems to be the most rigid implant for each type of loading essay, the mean values of the loading forces being the highest in the entire group. The intramedullary nail proved to be the most elastic implant on all types of

loading. In external rotation, the Dynamic Compression Plate - DCP gives surprisingly values of torsion forces relatively close to the longer locked plate (AxSOS - Stryker®). This seems to be related to the different “working length” of the different plates and also to the different total length of the implants. Regarding the advantages of indirect reduction and biological plate osteosynthesis, Livani and Belangero (Livani et al., 2004) developed MIPO technique by anterior approach in humeral shaft fractures. This MIPO technique avoids the problems related to the neural vascular structures of the arm and especially to the radial nerve. For proximal and middle shaft fractures they have used a proximal limited approach (between biceps - medially and deltoid muscle - laterally) and a distal approach between biceps and brahialis muscle (Fig. 1).

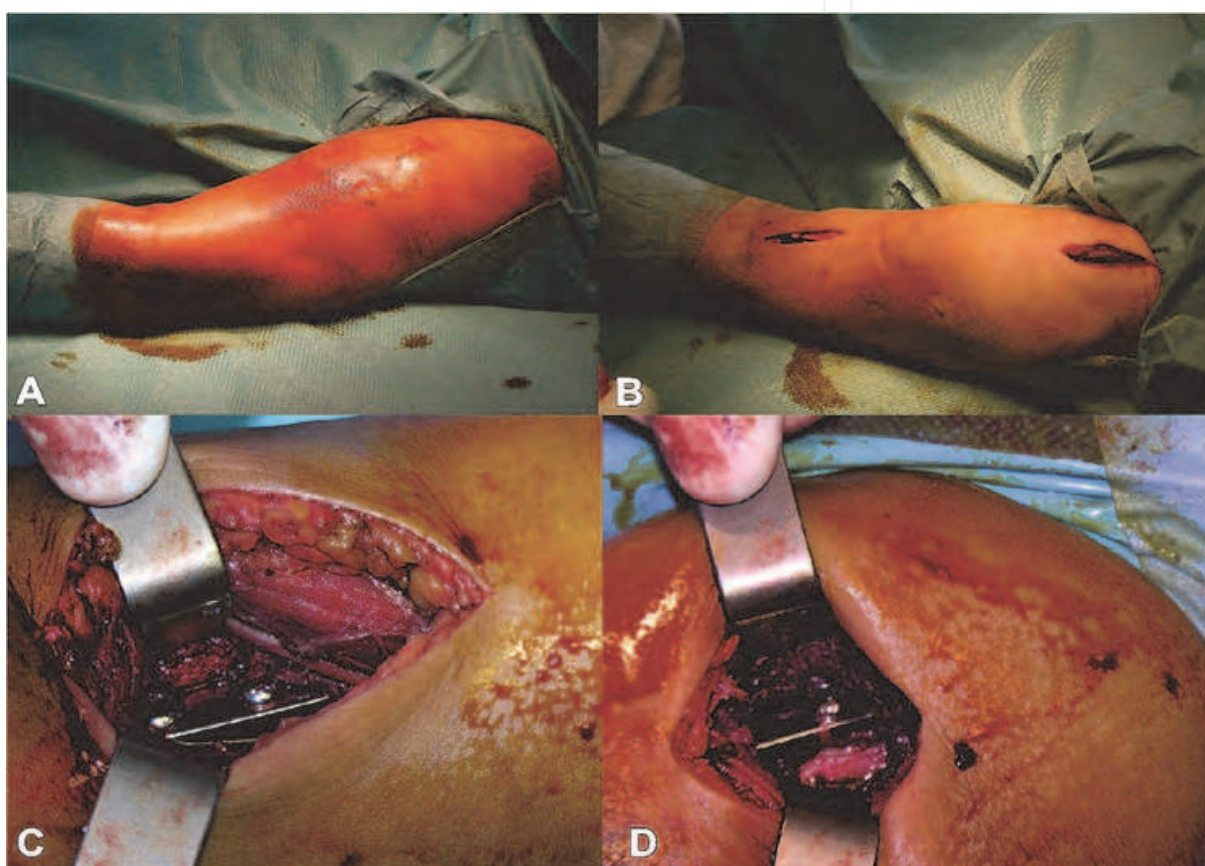


Fig. 1. (A-D) MIPO by anterior approach in a mid-shaft humeral fracture: (A) Arm positioning; (B) Proximal and distal approach; (C,D) Plate fixation

A DCP narrow plate with 12 holes and no previous molding was inserted from proximal to distal, placed on the anterior humeral face and fixed onto the shaft with at least 2 proximal and 2 distal screws. For distal fractures, they have used the same proximal approach and a distal limited approach performed by subperiosteal dissection of the lateral supracondylar ridge of the humerus, with retraction of brachioradialis and long carpal extensor muscle, as well as the radial nerve (even though unseen). A narrow DCP plate of 4.5 mm with 12 holes was molded and twisted medially to adapt to the anterior face of the humeral lateral column and diaphysis, thus avoiding occlusion of the coronoid or of the olecranon fossae. The plate was inserted from distal to proximal and fixed onto the shaft with at least 2 proximal and 2 distal screws, after reestablishing the humeral axis, length and rotation. The radial nerve may be endangered in the

lateral column approach but even in such circumstances its identification is not required. This technique can be used for fractures of the distal humerus with paralysis of the radial nerve. Following identification and restoration of the radial nerve through a separate approach, the molded plate is inserted from distal to proximal and fixed as previously described.

We have just finished a prospective study including 34 humeral shaft fractures (6 type 12-A, 8 type 12-B and 20 type 12-C/AO classification) treated with MIPO technique by anterior approach (using Livani and Belangero technique). We have used classic or narrow large fragment DCP plates of 10-14 holes, according to the fracture type. After a short immobilization (1-2 weeks) the patients started rehabilitation. All fractures healed within a mean time of 9 weeks following surgery, with good functional results regarding elbow and shoulder mobility (Fig. 2). There were no vascular or nerve complications, except 2 postoperative temporary paresthesia for the radial nerve in distal fractures.

The following tips and tricks are crucial in this technique : last distal screw – first inserted – relatively loose; arm abduction 60°; slide traction of the distal fragment, first proximal screw inserted, tightening the distal screw; clinical and radiological assessment; two more screws placed in each fragment; tightening the screws for pulling to the bone to the plate and reduction completion.

At the end of this study we can emphasize the advantages of this technique regarding safety and feasibility, without requiring special tools and demanding implants or excessive radiographic control. The plate stability allows a fast rehabilitation with superior functional results comparing with the conservative techniques. MIPO seems to be the best option for distal third humeral fractures and a viable solution for distal fractures with radial nerve palsy.

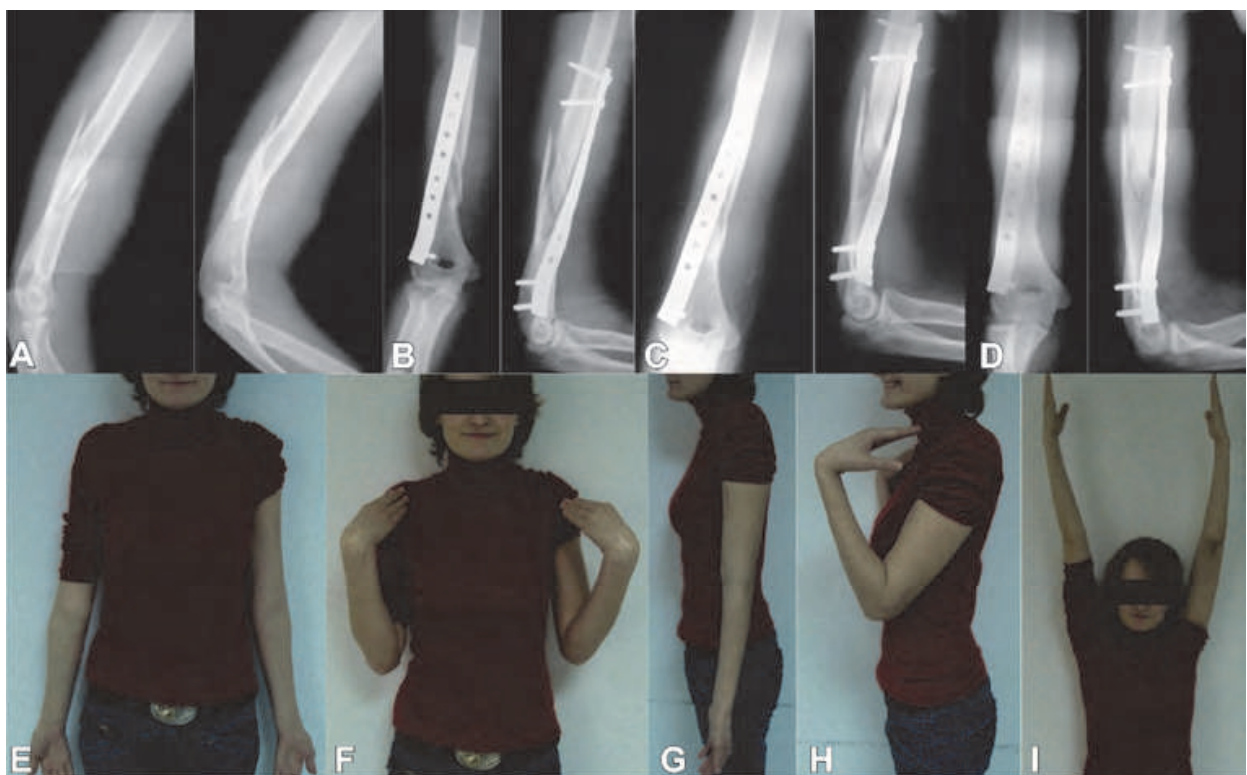


Fig. 2. Clinical case. Female, 23 Yrs, Distal Shaft Fracture type 12C / AO, luge incident; MIPO by anterior approach: (A) Preoperative aspect; (B) Postoperative aspect; (C) At 3 weeks; (D) Callus formation at 8 weeks; (E-I) Excellent functional recovery at 8 weeks.

3. MIPO techniques in complex subtrochanteric fractures

Subtrochanteric area is submitted to an eccentric biomechanical stress, and compression forces in the medial cortex are overwhelming compression forces in lateral cortical area (Hoffmann et al., 1999). Medial cortex comminution in high energy trauma involves major problems regarding reconstruction and internal fixation. Closed intramedullary osteosynthesis protects fragments vascularization better than plate osteosynthesis, giving special biomechanical improvements. The accurate implantation of these intramedullary constructs in subtrochanteric fractures is not an easy task, its difficulty being frequently underestimated.

MIPO by proximal and distal incisions was imagined by Wenda (Wenda et al., 1997) who used first a Condylar Blade Plate - CBP (Fig. 3), a single-unit construct that is difficult to be inserted in three plans at the same time, even with large incisions and femur visualization.

While the CBP was initially inserted with the blade pointing towards the surgeon, the MIPO technique was simplified by the use of the two-part and two-plane alignment achieved by Dynamic Condylar Screw (DCS) (Krettek et al., 2001). The technique consisted in 5 major steps (Fig. 4): 1. condylar screw insertion using minimal incision; 2. DCS-plate selection by fluoroscopy; 3. DCS-plate insertion beneath the vastus lateralis; 4. an additional minimal distal incision allows plate positioning and its slipping onto the condylar screw; 5. after the restoration of limb axis, length and rotation, the plate was fixed to the shaft with 3 or 4 screws placed divergently.

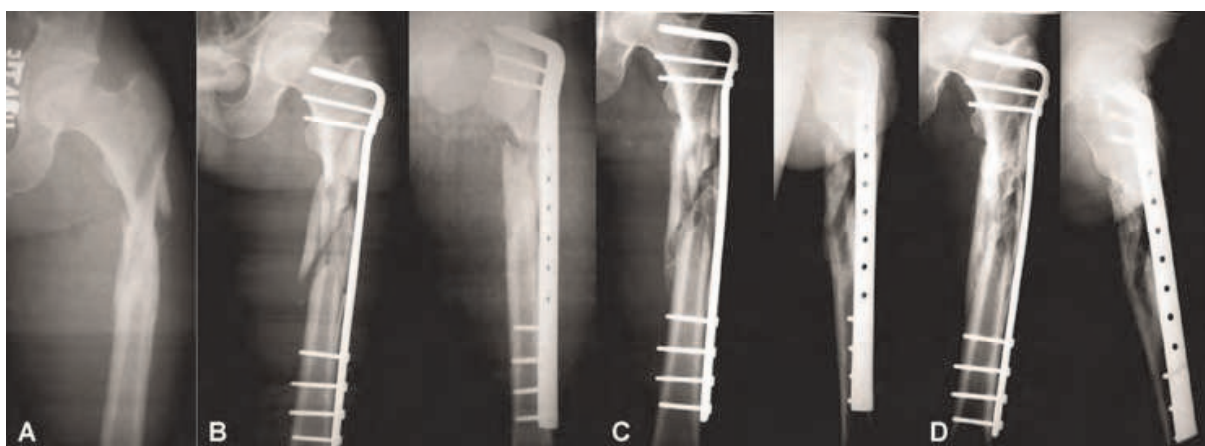


Fig. 3. (A-G): (A) Type IV (Seinsheimer) subtrochanteric fracture, with diaphyseal extension; (B) CBP minimally invasive osteosynthesis- postoperative control; (C) Callus presence at 2 months postoperatively; (D) Abundant callus at 6 months postoperatively.

Using special instruments, Krettek imagined MIPPO technique, implanting the DCS construct in a percutaneous and submuscular way (Krettek et al., 1997a).

We have performed a prospective study (Sirbu et al., 2008) in order to evaluate the outcome of 38 subtrochanteric femoral fractures treated by MIPO technique, using a 95° CBP in 7 cases, a DCS in 19 cases, a titanium-made Limited Contact-DCS (LC-DCS) (Fig. 5) in 11 cases and 1 reverse titanium-made Limited Contact - Condylar Buttress Plate (LC-CBtP). For reverse LC-CBtP the anterograde insertion under vastus lateralis was easily accomplished (Fig. 6).



Fig. 4. (A-J). (A) Complex subtrochanteric fracture; (B,C) MIPO with DCS, incipient callus at 2 months postoperatively; (D,E) Fracture healing at 4.5 months postoperatively; (F,G) Xray aspect at 1 year postoperatively; (H) Proximal incision; (I) DCS screw insertion; (J) Plate selection under RX control; (K) Plate insertion beneath the vastus lateralis; (L) Additional distal incision; (M) Final aspect of the operative wound.

The fractures were classified according to Seinsheimer (2 type IIB, 3 type IIC, 5 type IIIA, 4 type IIIB, 14 type IV and 10 type V). The crucial steps are represented by the reestablishment of axis, length and rotation of the femur, using Krettek techniques (Krettek et al., 1998): cable technique (in frontal plane), lateral fluoroscopic projection (in sagittal plane), the lesser trochanter shape sign - if intact (for rotational alignment) and meterstick technique (for length).

All fractures healed, within a mean time of 10.2 weeks (range 8-22 weeks). There were no infections or serious implant failure. One patient that fallen after operation undergone distal screw breakage with secondary displacement in varus, requiring re-intervention. At follow-up, there were 5 varus/valgus deformities above 5°, 4 leg length discrepancies over 15 mm and 1 malrotation of 20°. The final outcome (according to the Neer scale) was excellent in 24 cases, satisfactory in 13 cases and unsatisfactory in 1 case.

The conclusion was that this demanding technique has the advantages of a faster rate of union, with no need for bone grafting. Adjustment of adequate axial and rotational alignment is an essential aspect requiring careful attention.



Fig. 5. (A-F): MIPO with LC-DCS in a complex subtrochanteric fracture; (A) Preoperative Xray; (B,C) Intraoperative fluoroscopic control MIPO with LC-DCS; (D) Postoperatively Xray, with main fragments alignment; (E,F) Fracture healing at 4 months postoperatively



Fig. 6. (A-F): MIPO with LC-CBP in a subtrochanteric fracture. (A) Complex subtrochanteric fracture; (B) MIPO with LC-CBP, postoperatively Xray; (C,D) 1 month postoperatively, incipient callus in fracture site; (E,F) Fracture healing at 3 months postoperatively.

Even if the last generation of intramedullary nails and the locked proximal femoral plates represents the best alternative due to their biomechanical advantages, the elevated costs of these implants, the demanding technique of nailing in fractures with short proximal fragment and trochanteric extension, as well as our good results with a thorough biological technique using cheap classic implants led to the conclusion that MIPO with DCS is still a reasonable alternative in these difficult lesions.

4. MIPO techniques in distal femoral fractures

Complex distal femoral fractures represent a challenge for orthopaedic surgeons due to the comminution, soft tissue damage and complex intra-articular tracts (Wiss et al., 1999).

Open reduction and internal fixation – ORIF (early principles of the "Arbeitsgemeinschaft für Osteosynthesefragen" – AO) through a standard lateral approach was associated with large dissections, ligation of the perforating arteries and fragment devitalization, followed by a high incidence of infections, nonunions, iterative fractures and a need for bone grafting (Schatzker et al., 1979; Sirbu, 2007). The idea of splinting with intramedullary implants in diaphyseal fractures of femur and tibia and the associated biological response despite non-anatomical reduction prompted the usage of plates in a similar manner and the concept of biological plate osteosynthesis have radically improved the treatment of complex meta- and epiphyseal fractures (Krettek et al., 2001). New types of surgical techniques, starting with indirect reduction and continuing with MIPO (Krettek et al., 2001), MIPPO (Krettek et al., 1997a) and TARPO (Krettek et al., 1997b) for intraarticular distal femoral fractures have the advantages of a faster rate of union, with no need for bone grafting (Krettek et al., 2001).

We have evaluated the outcome of 25 extraarticular fractures of the distal femur (type A2-A3/AO) treated by MIPO technique, using a CBtP (8 cases from which 4 cases LC-CBtP) (Fig. 7), DCS (13 cases from which LC-DCS – 5 cases)(Fig. 8), premolded Dynamic Compression Plate - DCP (3 cases) and Chiron Utheza plate – 1 case (Sirbu et al., 2008). The plates were carefully inserted through limited distal and proximal incisions only, beneath the vastus lateralis. They were fixed with screws after establishing the adequate limb alignment, length and rotation. All fractures healed within a mean time of 11.4 weeks. The functional outcome was excellent in 15 cases, satisfactory in 9 cases and unsatisfactory in one case. The authors concluded that MIPO technique is safe and has the biological advantage of a faster rate of union, with low complication rate.

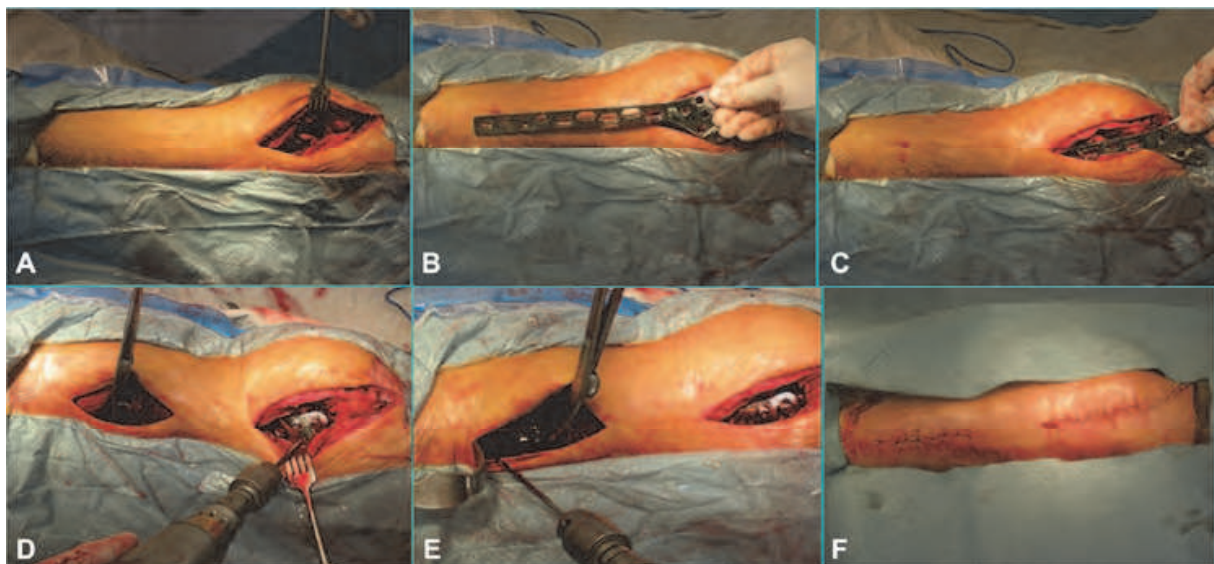


Fig. 7. (A-F) MIPO with limited proximal and distal incisions only, in a distal femoral fracture. (A) Antero-lateral approach; (B) Plate selection under fluoroscopic control; (C) Retrograde plate insertion beneath the vastus lateralis; (D) Plate distal fixation; (E) Plate proximal fixation, by additional incision; (F) Final operative wound aspect.

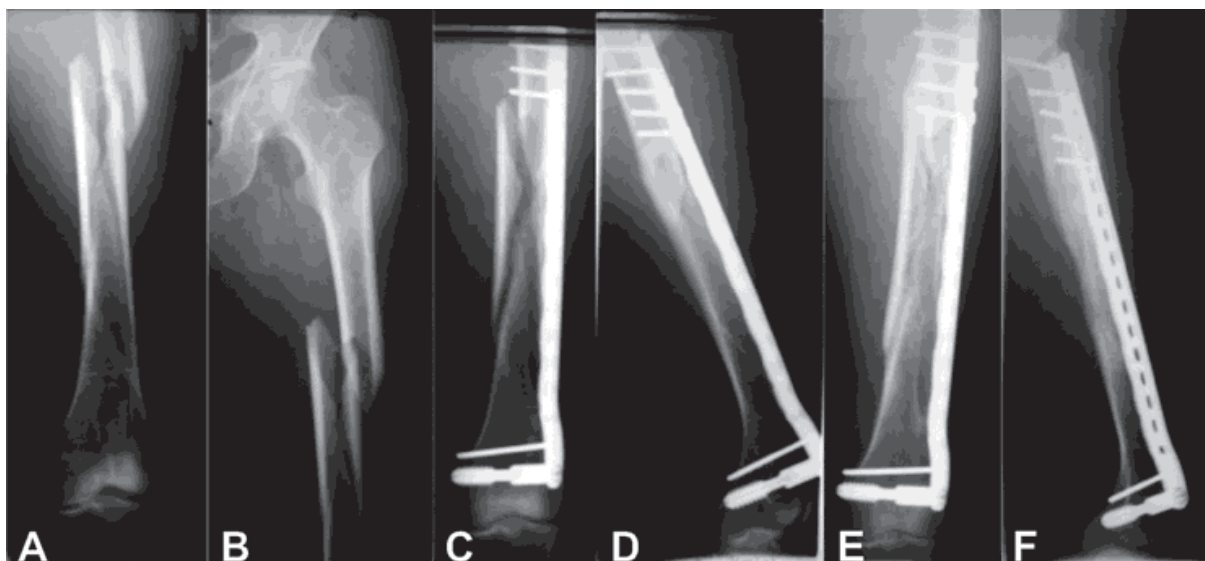


Fig. 8. (A-F). Supracondylar fracture of the left femur, with diaphyseal extension; MIPO with LC-DCS: (A,B) Preoperatively aspect; (C,D) Postoperatively aspect; (E,F) Callus formation at 6 months postoperatively

The ideal implant for the distal femur fractures is controversial. However, while plates with angular stability (types LISS and LCP) and retrograde interlocking nail seem to be the best choice for treatment, CBP and DCS still represent the most used implants, due to their biomechanical and financial advantages. In a biomechanical study we have performed a comparative study on plastic bones regarding the mechanical stiffness of the bone/osteosynthesis material (DCS or CBP) construct in complex supracondylar femur fractures (Sirbu et al., 2009a). These complexes were tested for 7 load types.

Compression force and loading force were measured by a force transducer and linear deformation values for the compression (Fig. 9) were measured by two inductive transducers applied in frontal axis (TD1) and sagittal axis (TD2).

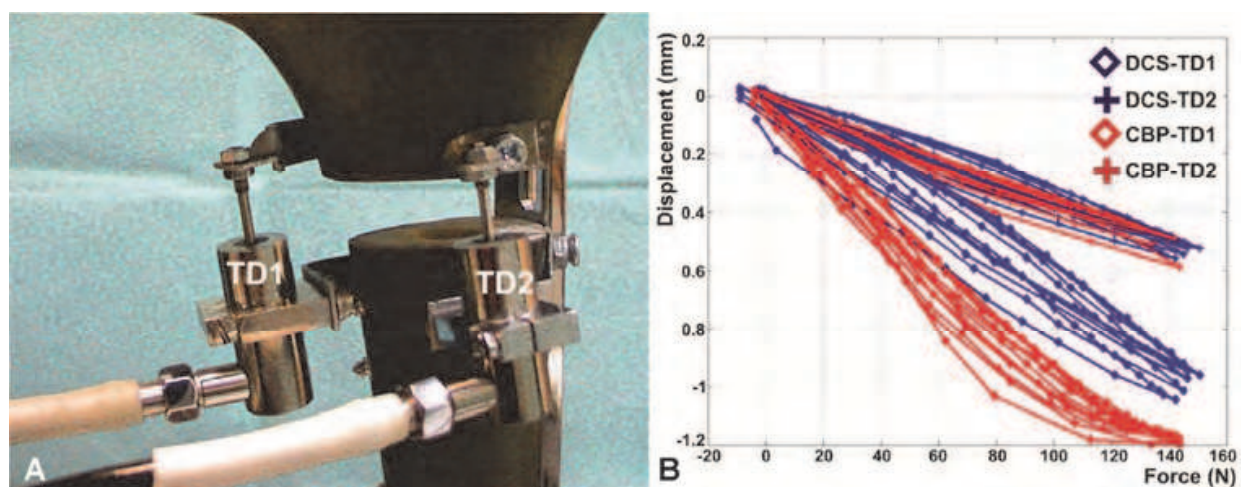


Fig. 9. (A) Deformation measuring methods. Transducers: TD1 – frontal axis; TD2 – sagittal axis; (B) Internal compression (DCS/CBP). Six loading tests. TD1 deformations, 12-16% higher for CBP than DCS; TD2 deformations, comparable for CBP vs DCS. Negative values (osteotomy closure). Mechanical hysteresis (both implants)

The femur-DCS complex is more stable in all compression types except the posterior and axial one, where CBP appear to be more resistant for TD2 transducer.

By changing the instruments required to insert the DCS construct, Krettek (Krettek et al., 1997a) has imagined the MIPPO technique for the proximal and distal femur (fig. 10). The key for this procedure is the usage of a two-part DCS implant.

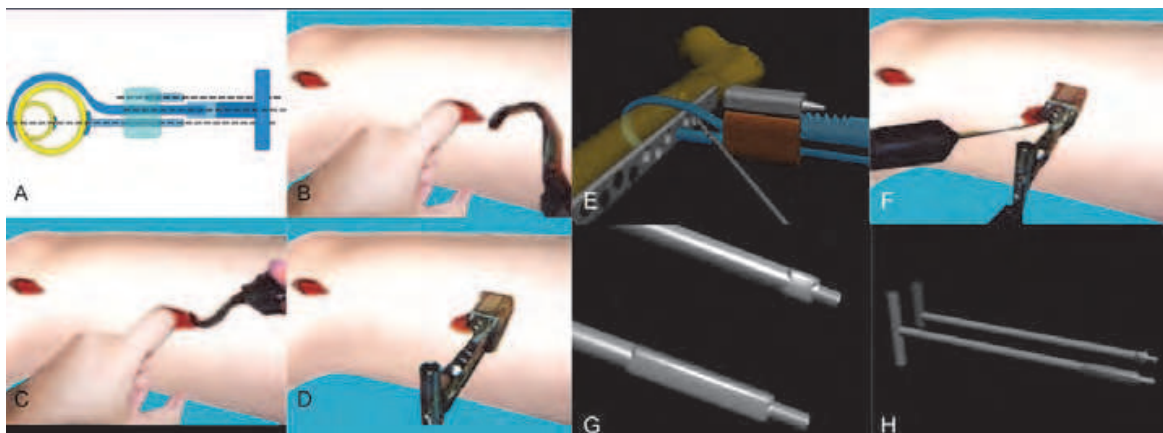


Fig. 10. Special instruments used in MIPPO of the distal femur

In complex supra- and intercondylar fractures, the exposure and direct reconstruction of the joint surface helped by the maintenance of a minimally invasive technique for the metaphyseal-diaphyseal part are procedures difficult to be performed by classic lateral approach; this requires a medial placement for the retractors in order to visualize the articular comminution (mainly posteromedial), with consecutive metaphyseal deperiostation and healing delay. Moreover, the knee flexion determines the patella pressure in the medial condyle associated with its secondary displacement.

For a complete joint visualization and to limit soft tissue dissection in the metaphyseal-diaphyseal areas, Krettek (Krettek et al., 1997b) introduced TARPO.

A very strict external parapatellar arthrotomy if extended proximally (by separating the rectus femoris from vastus lateralis) and distally (up to the tibial tuberosity), allow medial patella displacement with direct and anatomic reduction of the articular surface (Fig. 11). The articular condylar area is then indirectly reduced to diaphysis by a retrograde inserted plate, beneath the vastus lateralis (without the exposure of the metaphyseal-diaphyseal area and without tempting an anatomical reduction). The plate is fixed proximally to diaphysis by screws that are inserted percutaneously or by minimal incisions (Fig. 12).

We have performed a prospective study in order to evaluate the outcome of 27 displaced complex AO type C2-C3 distal femoral fractures treated by TARPO procedure (Sirbu et al., 2008). There were 20 closed and 7 open fractures (3 grade I, 3 grade II and 1 grade IIIA, according to Gustilo classification). All fractures healed, within a mean time of 12,2 weeks (range 8-20 weeks). We have recorded 1 infection, 1 delayed union, 2 distal implant failures with secondary varus (1 case with infection). We have to reoperate in 3 cases. The results (using the Neer scale) were excellent in 14 cases, satisfactory in 8 cases, unsatisfactory in 4 cases with 1 failure. At follow-up there were 5 varus-valgus deformities exceeding 5°, two leg length discrepancies over 1,5 cm and one malrotation of 15°.

The conclusion was that this demanding technique has the advantage of a faster rate of union, no need for bone grafting and improved exposure of the knee joint. Care should be taken to ensure adequate axial and rotational alignment.

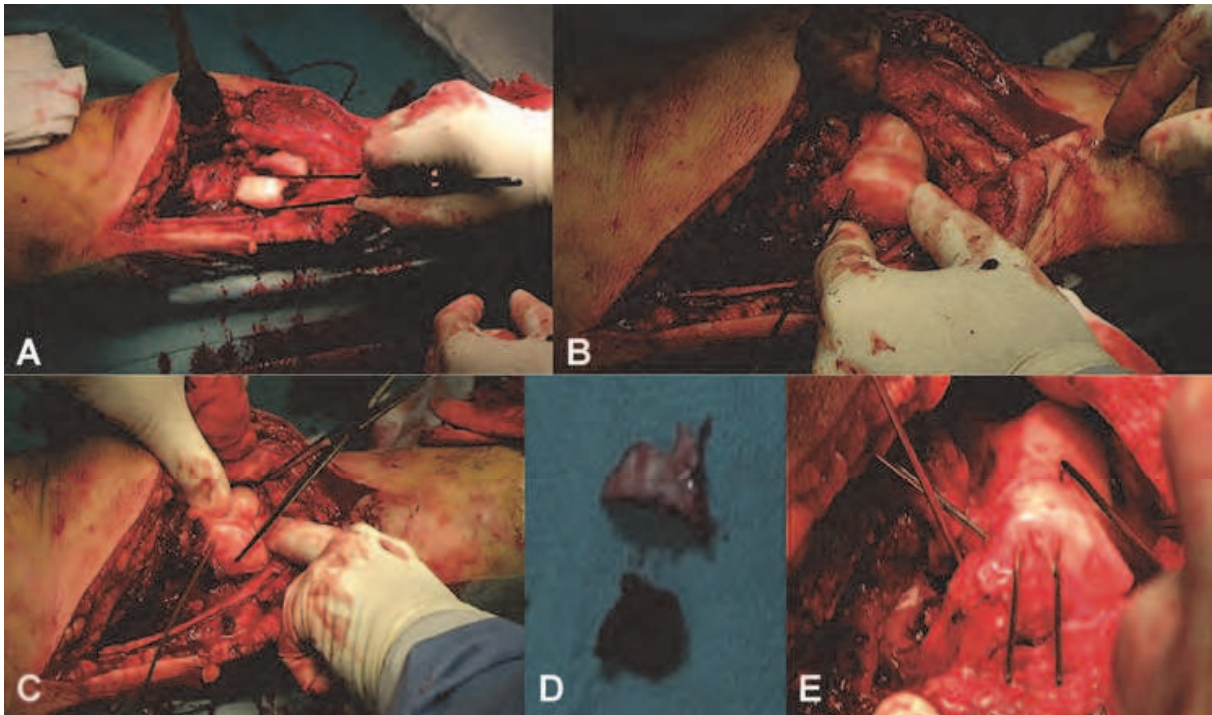


Fig. 11. (A-E) TARPO technique: (A) lateral parapatellar arthrotomy and fracture site inspection; (B-E) anatomical reduction of the articular block and fixation with Kirschner wire with (D) removal of shattered bone fragments.



Fig. 12. (A,B) Fracture type C2/AO with diaphyseal extension; (C) TARPO with classic DCS, postoperatively aspect with perfect fracture fragments alignment; (D,E) Fracture healing at 5 months postoperatively, with an abundant callus in the fracture site. Uneventful healing at 5 months, despite extreme comminution of the metaphyseal area.

A major problem of the minimally invasive surgical techniques is that the classic implants (CBP, CBtP and DCS) are not specially conceived for the percutaneous implantation, and so the procedures are demanding (Krettek et al., 1997b; Sirbu, 2007; Sirbu et al., 2008). On the other side, Frigg (Frigg et al., 2001a, 2001b) have emphasized three problems during internal

fixation with classic plates and screws: primary displacement of the fragments, secondary displacement and periosteal compression that determine the reduction of the blood flow (fig. 13).

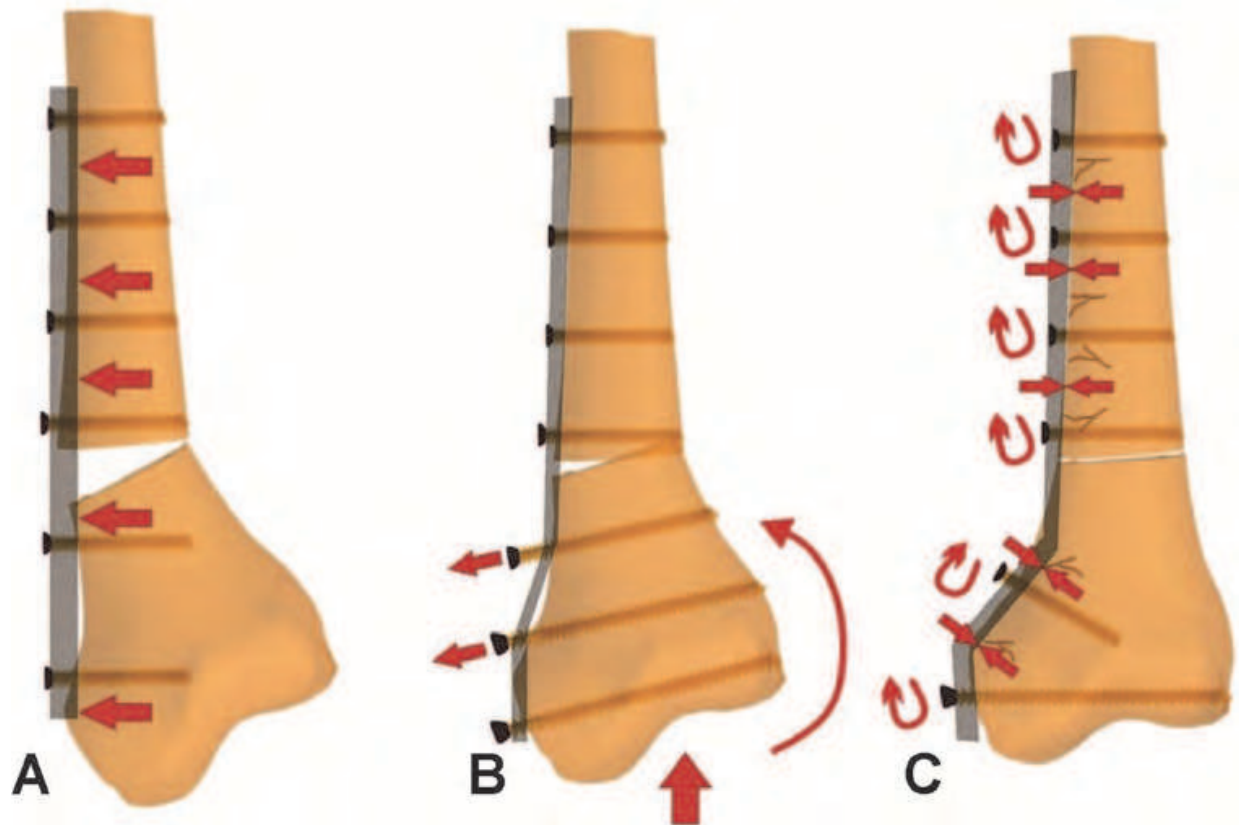


Fig. 13. (A-C) Complications for the fixation with classical plates: (A) Immediate fragment displacement; (B) Secondary displacement; (C) Periosteal compression.

The combination of three imperative criteria (biomechanical aspect of the stiffness bone-implant, anatomical reduction of the articular surfaces, axis, length and rotation reestablishment with minimal devascularization for the femur and percutaneous insertion of the implant) have led to the development of a new generation of locked plates and instruments for meta- and epiphyseal fractures. They were denominated Less Invasive Stabilization Systems - LISS (fig. 14A) and have been initially destined for the distal femur (LISS-DF) and then for proximal tibia (LISS-PLT) (Krettek et al., 2001; Frigg et al., 2001a). The next improvement for this type of plates with angular stability was represented by the Locked Compression Plates - LCP (Frigg et al., 2001b).

The high performance LISS-DF combines perfectly the aspects of a CBtP with the advantages of a fixed angle of a DCS system and with the characteristics of a Point-Contact Fixator (PC-Fix). LISS-DF system is formed by a titanium plate with an anatomical contour with round threaded holes in which the threaded head of the monocortical self-taping self-drilling screws are locked. Even if it does not participate to axis reestablishment due to multiple fixed angle screws, the LISS system behaves like an internal fixator (Sirbu, 2007; Sirbu et al., 2008; Frigg et al., 2001a, 2001b). While in classic plates (Fig. 15A) the system stability results from the frictional forces between bone and implant (requiring bicortical screws), for the internal fixator the forces that act on the bone are being transferred to the

fixator by the connection between the screws threaded head and the holes in the plate (Fig. 15B).

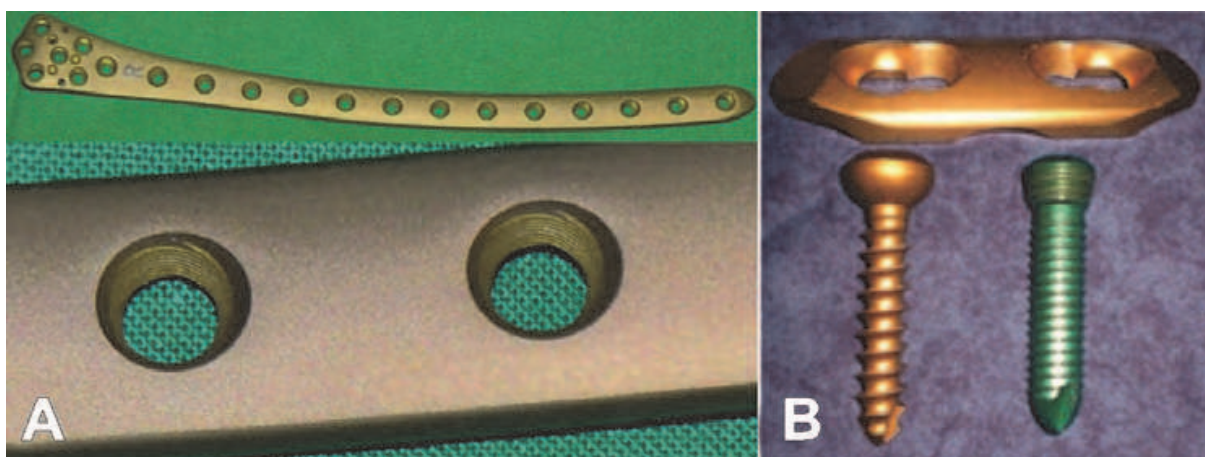


Fig. 14. Plates with angular stability. (A) LISS-DF; (B) LCP.

The screw lock in the implant holes determines the stability increase and eliminates the risk of the reduction loss due to eventual screws lag in the plate. Moreover, the periosteal blood supply is conserved due to the absence of the contact between the bone and the fixator (Frigg et al., 2001a)

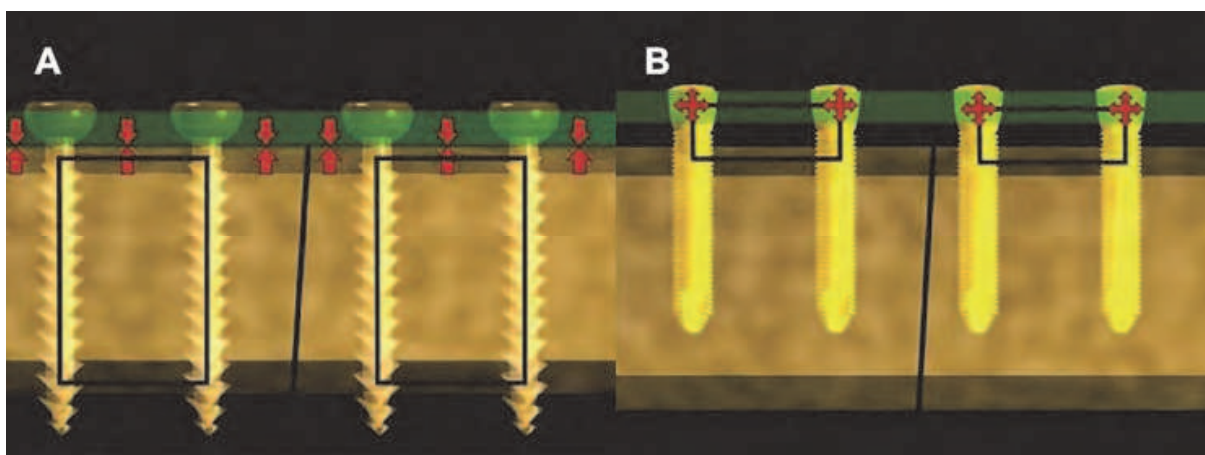


Fig. 15. Differences between distribution of the biomechanical load for standard plates (A) by comparison with LISS (B) and the bone implant interface.

The restriction of the round hole of LISS-DF led to the development of LCP-DF with combi-hole. Half of the hole is formed by a "dynamic compression unit" whose purpose is to allow the usage of standard screws; the other half is conical and threaded, allowing the usage of the special threaded head screws (Locking Head Screw-LHS). This leaves the decision of which screw to use after having chosen the plate (Mayo, 2005); the combi-hole confer the opportunity of variation without changing the implant.

In a recent study (Sirbu et al, 2009b) we have shown the biomechanics of the internal fixators as well as an evaluation of the results in treating the complex distal femoral fractures using these systems. The clinical study included 15 fractures (3 type A2, 5 type A3, 4 type C2 and 3 type C3/ AO).

Two fractures were above total knee prosthesis. Three patients presented open fractures: 1 type I, 1 type II and 1 type IIIA, according to Gustilo classification. We have used 10 LISS-DF and for the other 5 cases, LCP-DF system. For extraarticular fractures we have performed a 6-8 cm distal anterolateral approach (Fig. 16, 17) while for intraarticular fractures we used an anterior approach with lateral parapatellar arthrotomy (Fig. 18, 19).

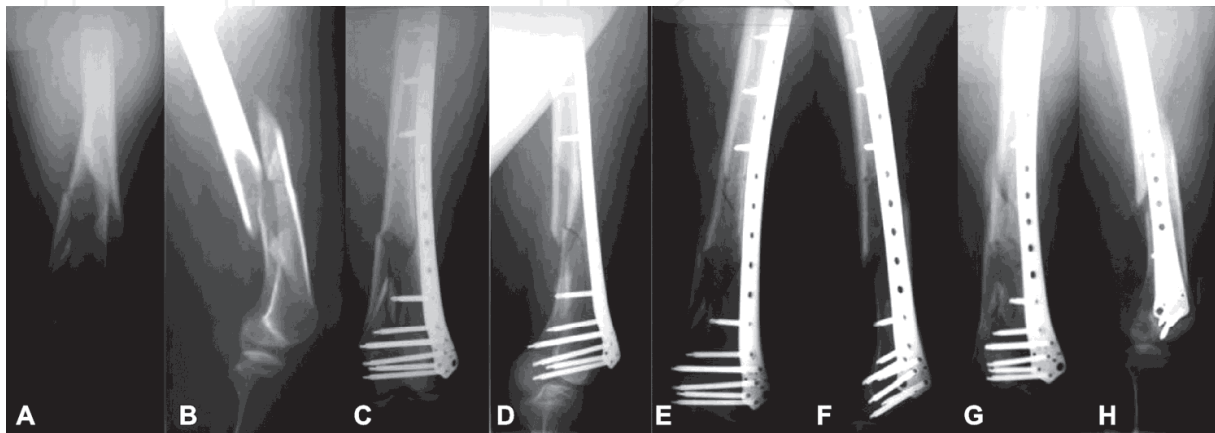


Fig. 16. A3/AO distal femoral fracture; 39 years old patient with systemic scleroderma; MIPO with LISS-DF; (A,B) Preoperative; (C,D) Postoperative; (E,F) 1 month postoperatively with slight callus; (G,H) 4 months postoperatively with fracture healing

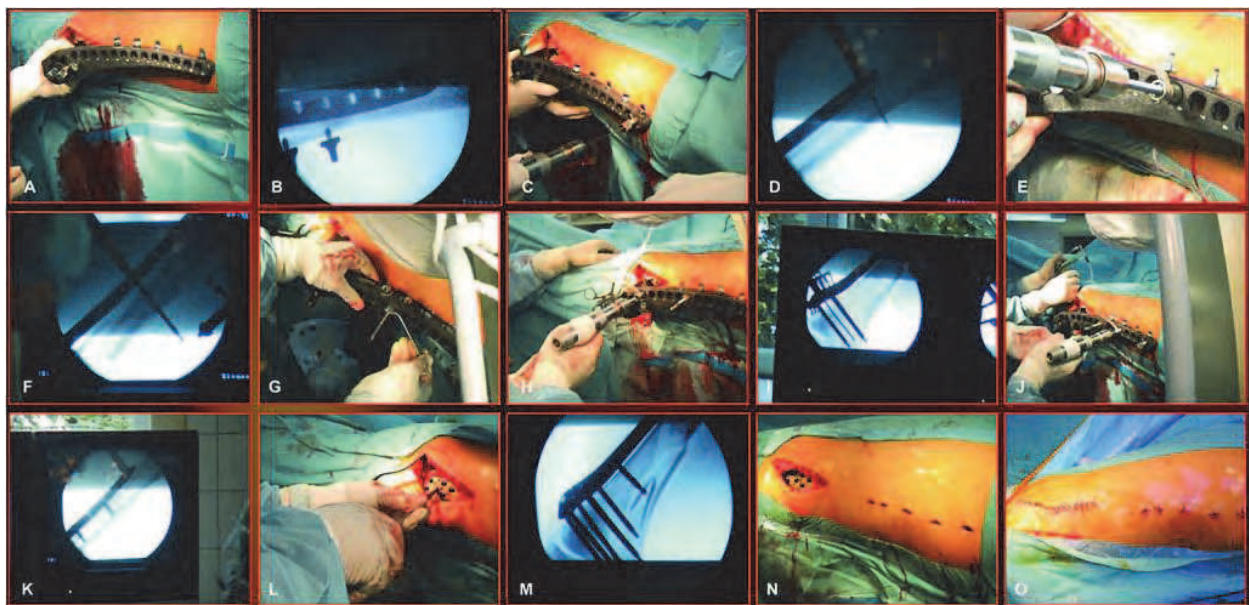


Fig. 17. (A) Limited antero-lateral incision, insertion of LISS; (B) Fluoroscopic check of the proper plate position; (C,D) Proximal fixation with a wire; (E,F,G) Whirly-bird insertion and reduction improvement; (H,I) Distal fixation with locked self drilling and self tapping screws, using cooling system; (J,K) Proximal fixation with unicortical LHS; (L,M) Insertion of the last distal screw through hole A (after removing the insertion guide); (N,O) Final aspect.



Fig. 18. (A) Distal femoral fracture C3/AO open type IIIA with bone loss; (B) Damage control with external fixation; (C,D) TARPO with LCP-DF; (E,F) Xray aspects at 6 weeks; (G) Xray aspects at 10 weeks; (H) Bone grafting and bone substitute; (I) Healing at 2 months from bone graft.

The steps for the surgical technique using LISS-DF (Fig. 17) or LCP-DF (fig.18) are: 1. anatomical reduction of the condyle using special instruments (collinear reduction clamp) in order to achieve interfragmentary compaction with lag screws (fig.19); 2. Close reduction of the metaphyseal and diaphyseal fracture with restoring of the length, rotation and alignment, keeping in mind that the LISS and LCP plate are not meant to aid in reduction and they only hold fragments in place; 3. the plate insertion between the periosteum and the muscle with the aiming device; 4. fluoroscopic control of the alignment and the position of the plate on the diaphysis; 5. provisional plate fixation with proximal and distal Kirschner wires; 6. whirly bird special tool insertion which bring the diaphysis to the plate, revise the reduction in frontal plan and prevent the medial diaphyseal displacement by self drilling/self-taping screws insertion; 7. insertion of the distal locked screws using the distal holes of the aiming device; the length of the screws can be found on a table according to the width of the femoral condyle that have been measured preoperatively; 8. the insertion of the self-drilling/self-taping monocortical diaphyseal screw, using stab incisions; 9. Continuous

check of the axis and rotation; 10. Removal of the aiming device and eventual insertion of a distal LHS in the hole A.

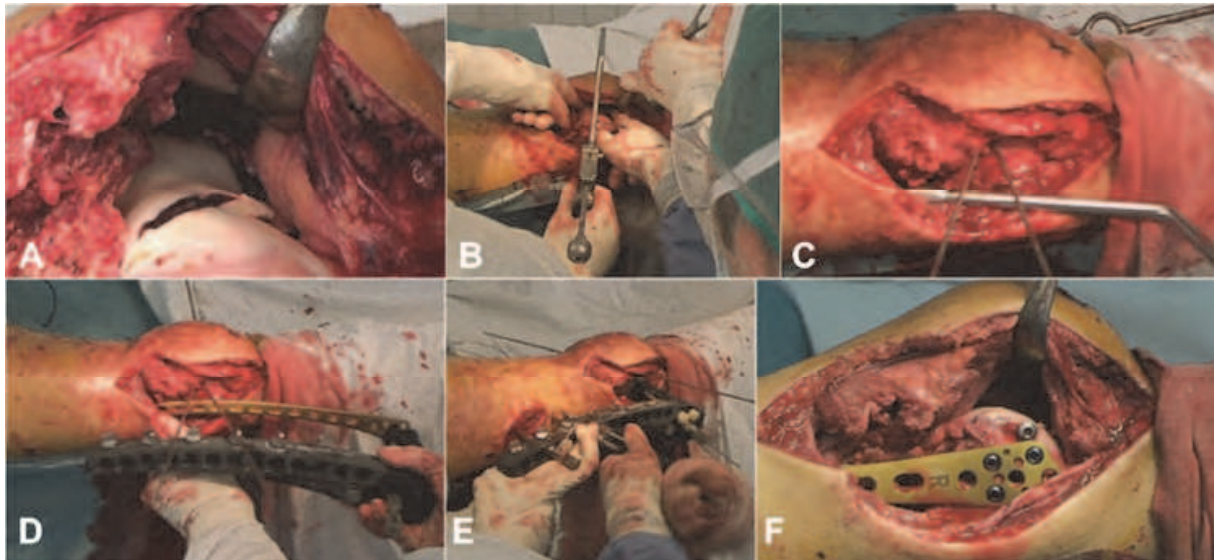


Fig. 19. (A) Parapatellar arthrotomy; (B) Reconstruction of the articular block using a collinear reduction clamp; (C) Tunneling with special instruments; (D) LCP-DF insertion with aiming device; (E) Diaphyseal fixation with monocortical screws (tightening with torque limited screwdriver); (F) Final aspect.

All patients were followed for at least 1 year. The fractures healed within a mean time of 12,4 weeks (with limits of 7-20 weeks) without primary or secondary bone grafting in 14 cases. For 1 case with open type 3A and bone loss, we have performed, at 3 months postoperatively, secondary bone grafting combined with osteoconductive bone substitution with uneventful healing at 5 months (Fig. 18). There were no infections or implant failures. According to the Neer scale, 10 patients had excellent results, while the other 5 had satisfactory results.

Our experience based also on literature data (Kregor, 2005) led to some tips and tricks gathering: 1. The usage of longer plates with spaced screws instead of short plates; 2. Perfect positioning of the plate on diaphysis (misplacement determines the fixation failure of the monocortical screws and the poor anchorage); for these reasons, a limited incision on the last holes in the plate (with visualization and manual palpation) is recommended for the obese patient or for plates with 11-13 holes; 3. Usage of bicortical screws for severe osteoporosis; 4. Perfect knowledge on the operative technique and instruments and of the anatomy of the distal femur; 5. Position of the distal region of the implant very close to the lateral condyle in order to avoid the irritation of the ilio-tibial tract.

In conclusion, these preliminary results showed that LISS-DF and LCP-DF represent an improvement of percutaneous techniques. With a good knowledge of the operative technique and careful preoperative planning, these systems represent an excellent, safe procedure, for the treatment of almost all distal femoral fractures. Care should be taken to insure a proper closed reduction before stabilization by locked plates. Even if the authors prefer the LCP system due to its versatility and combi-holes, LISS-DF and LCP-DF provide a unique answer in complex fractures type C3/AO with distal short fragments, fractures on osteoporotic bone, fractures above knee prosthesis and even open fractures.

One of the disadvantages of the monoaxial angular stability plates is represented by the preformed angle of the threaded holes; thus, the locking screw orientation is dictated by the plate design. Polyaxially locked plates allow the adjustment of screw trajectory, their placement being adapted to the fracture type (Richter et al., 2006; Sirbu et al., 2009b, 2010). The screw position can be changed with 15° in any direction inside a solid cone (with a 30° allowance)(Fig. 20).

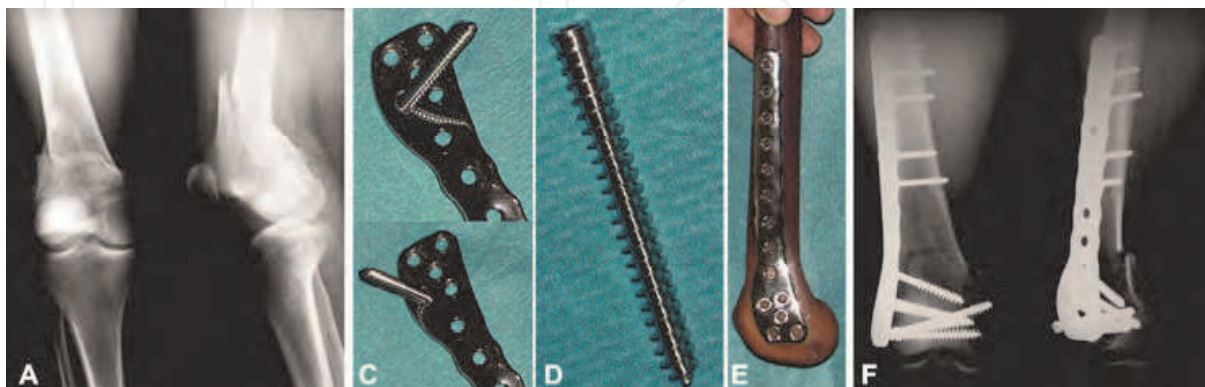


Fig. 20. TARPO with Numelock polyaxial locked plate in a distal femoral fracture type C3/AO.

However, the best option for screw locking is controversial and insufficiently investigated. The authors present in a recent study (Sirbu et al., 2010) their personal experience regarding angular stability plate osteosynthesis for the fractures of the proximal humerus, distal radius, distal femur, proximal tibia. Results for the treatment with internal fixator plates are much better than the results for classic implants osteosynthesis (mainly in fractures on osteoporotic bones), accounting for construct stability, lack of secondary displacements, early rehabilitation. The authors' experience shows that LCP plates are preferred and the newer polyaxial locked plate faces to the internal fixator with round thread holes due to the ability to choose the screw type and its trajectory.

5. MIPO techniques in proximal tibial fractures

Complex fractures of the proximal tibia represent severe lesions that raise treatment problems. In displaced or unstable complex fractures (with/without articular involvement) the main indication is represented by the plate osteosynthesis (White et al., 2000). The incidence of tegumentary necrosis, nonunions and infections is increased especially for the extended external and medial approach. These complications induce a decrease of the local blood flow due to excessive deperiostation and fragment devitalization. The disadvantages of the external placed plates determined authors as Krettek (Krettek et al., 2001b) to introduce MIPPO technique by medial approach. The main advantages are represented by the ease of molding technique and the subcutaneous placement, without deperiostation or blood flow limitations (Sirbu et al., 2006)(Fig. 21).

In a prospective study (Sirbu et al., 2008) we have presented the preliminary results using a medial approach and MIPO for complex proximal extraarticular fracture of tibia. 12 fractures in 12 patients (9 males, 3 female) were investigated. The fractures were classified according to AO/ASIF (4 cases with 42-C1 type, 3 cases with 42-C2 type and 4 cases with 42-C3 type). There were 5 open fractures (3 of Grade I, and 2 of Grade II, Gustilo).



Fig. 21. (A-F) MIPO proximal tibia - medial approach: (A) Plate premold and torsion; (B) Limited proximal incision and tunneling by clamp; (C) Plate insertion; (D,E) Plate proximal fixation by screws; (F) Proximal and distal incisions for percutaneous plate fixation

After alignment of the fracture by indirect reduction, the plate is introduced through a short incision beneath the skin, and pushed distally on the medial aspect of tibia. The bridging plate is initially fixed proximally, the alignment is checked using fluoroscopy and finally, the plate is fixed distally (with percutaneous divergent screws) (Fig. 22).

11 fractures healed, within a mean time of 15 weeks, while we have registered only 1 “tight” nonunion; there were no infections, skin troubles or implant failures. Two fractures healed with larger than 5° of varus, 2 with valgus over 5° , 1 with more than 10° recurvatum but the other 7 achieved an acceptable alignment. For nonunion we have performed plate removal and Ilizarov external fixation. In 6 cases we have removed the plates. All patients had a satisfactory knee movement range. The conclusion was that this demanding technique represents a reasonable alternative to the lateral approach in proximal fractures of tibia but it requires practice and experience in indirect reduction techniques.

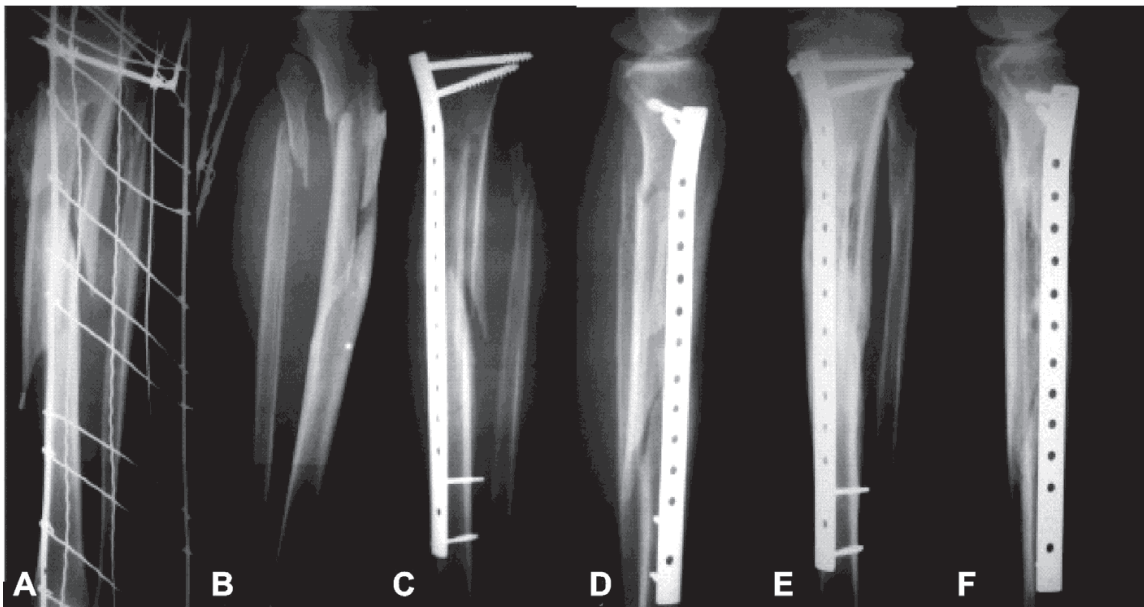


Fig. 22. Diaphyseal tibial fracture type 42-C with proximal extension; internal fixation by MIPO technique; (A,B) preoperative radiographs; (C,D) postoperative radiographs; (E,F) 1 year postoperatively

While MIPO with classic plates has determined the result improvement, the angular stability plate type Less Invasive Stabilization System – proximal lateral tibia (LISS-PLT) or Locked Compression plate (LCP-PLT) were specially designed for this kind of fractures.

In a published study from 2009 (Sirbu et al 2009c) the authors emphasize the design of the plate, the concept of the internal fixator and the importance of the aiming device for percutaneous insertion. There were investigated 8 fractures of the proximal tibia in 8 patients, with a mean age of 39.5 years. Fractures were classified according to AO/ASIF in 2 type A3, 2 type C1, 2 type C2 and 2 type C3). There were three open fractures (1 type I and 2 type II) according to Gustilo. In all 8 cases we have performed minimally invasive plate osteosynthesis, using a LISS-PLT system in 5 cases (Fig. 23) or a LCP-PLT in 3 cases.

We have used either a curved incision or a strait incision from the Gerdy tubercle about 50 mm in distal direction. The anterior tibial muscle was detached 1 cm from the tibial ridge, allowing the LISS plate insertion between periosteum and bone. For complex intraarticular fractures we have performed first an indirect reduction and the bone defect was filled with bone substitute (Fig. 24). The postoperative X-rays and the follow-up showed an excellent reestablishment of the axis with a good stability of the bone-device complex, despite the monocortical screws in the diaphysis.

All fractures healed after a mean time of 13 weeks (range 8-22 weeks) without bone grafting. At the most recent follow-up, all patients were fully weight bearing without crutches with good knee mobility (mean knee flex-ion 105°; range 95-140°). There were no infections or implant failures. Even if there is a correlation between fractures type C3/AO and a moderate functional result, it seems that the age does not influence the functional outcome.

Even if the study was limited, the authors experience with MIPO with classic plates in proximal tibia and the present results with MIPPO with LISS-PLT and LCP-PLT allow them to consider the internal fixators as “ideal” for these difficult lesions.

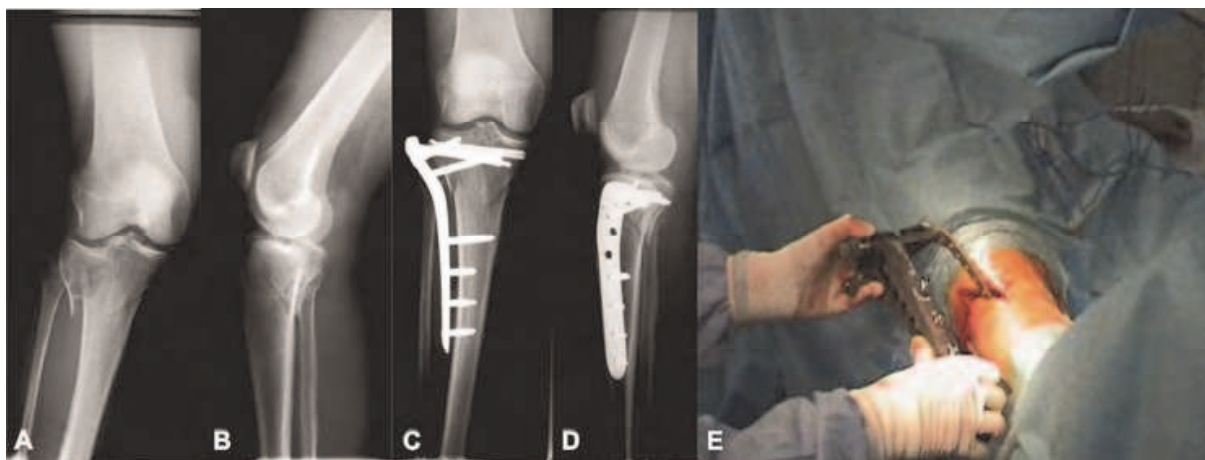


Fig. 23. (A,B) Proximal tibia fracture C1/AO (C,D) MIPPO with LISS PLT.(E) LISS-PLT with aiming device, made of carbon reinforced PEEK; LISS insertion through a limited curved approach, beneath the anterior tibial muscle.

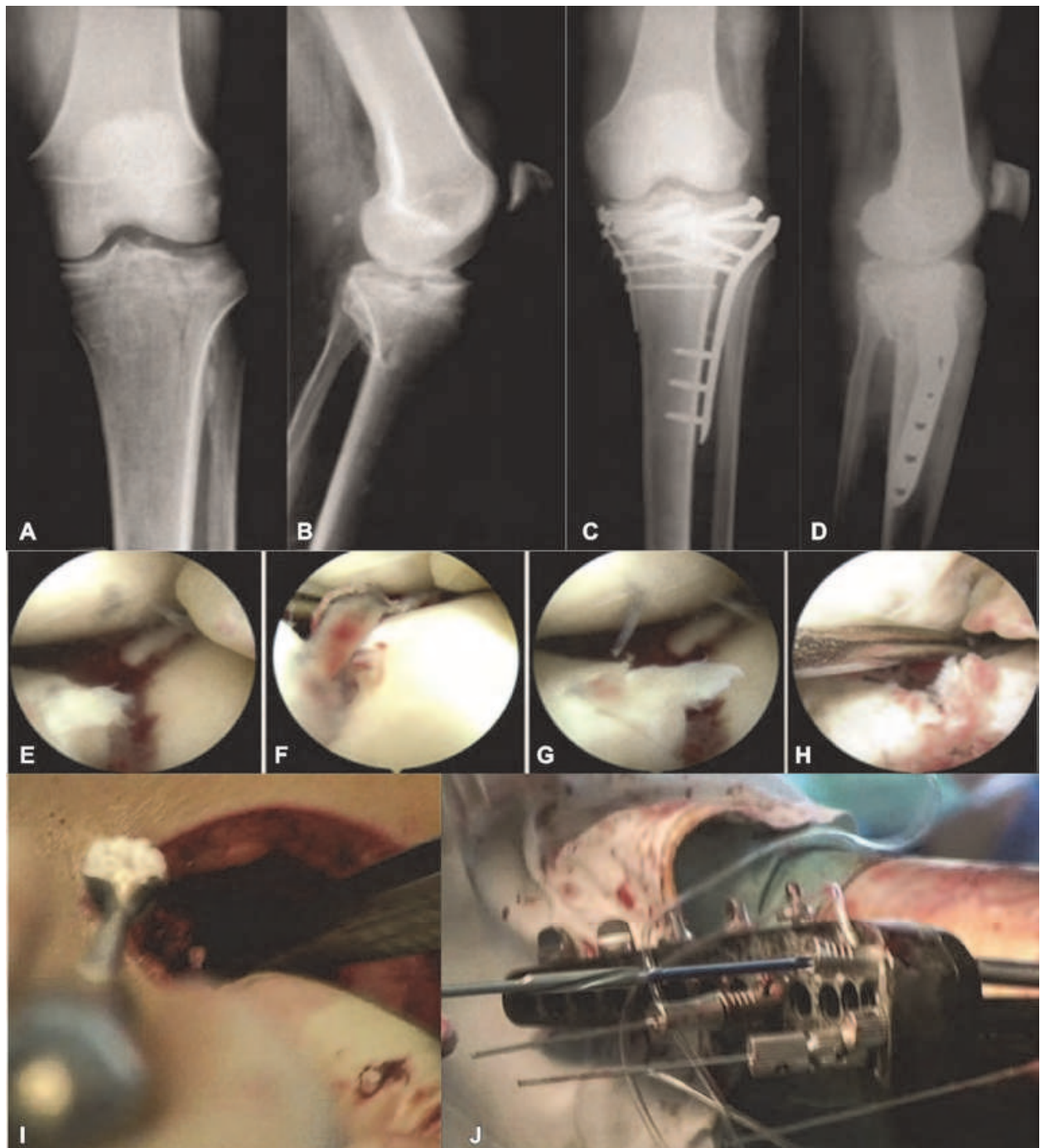


Fig. 24. (A-J) Proximal tibia fracture (type C3/AO): (A,B) preoperative aspect; (C,D) medial approach, reduction of the articular surface, small T-plate, lateral approach, close reduction, LCP-PLT, bilateral filling with Eurocer - postoperative aspects; (E,H) arthroscopic reduction control; (I) defect filled with Eurocer granules; (J) internal fixation with LCP-PLT on the lateral side.

6. MIPO techniques in distal tibial fractures

Distal tibial fractures show some characteristics as: hardship regarding reduction and stabilization, an increased local complication rate following classic osteosynthesis by

metallic plates (nonunions, infections, tegumentary necrosis) and also consecutively to intramedullary osteosynthesis (malalignment) or to external fixation (healing delay).

On one side, MIPO shows the advantage of periosteal circulation preservation with positive effect on bone healing (Baumgaertel et al., 1998; Farouk et al., 1997), and on the other side, it provides a good stability for the fracture site. Promising results for MIPPO procedure in proximal and distal femur recommended this technique for distal tibia too (Helfet et al., 1997). According to Helfet, the standard protocol that precedes MIPO procedure includes: a. tibial fracture alignment with external triangular temporary fixation, extended from heelbone to tibia; b. reduction of the fibular fracture and plate fixation by a precontoured third tubular plate or by a DCP 3.5 mm. MIPO by medial approach is recommended at 5-7 days from accident; type 1 and 2 (Gustilo) open fractures does not represent contraindications. As implants, we may use 4.5 mm DCP plates, LC-DCP, LCP or semi-tubular plates. Preoperatively, these plates are molded on the plastic tibia, a copy of the anatomical tibia. Patients can be operated on a radiolucent operative table or on orthopaedic table (with transcalcaneal nail). A medial approach is performed, by two limited incisions, distal and proximal from the fracture. To maintain reduction we recommend a sharp autostatic nipper that provides the transcutaneous fracture contention (Fig. 25). Percutaneous insertion of the pre-molded plate is performed only from the distal to the proximal wound, either directly, or following a subcutaneous tunneling with blunt scissors. Subcutaneous plate progress is performed by a Kocker clamp or by other devices (Fig. 25). The plate is fixed with 4.5 mm cortical screws, usually with 3 proximal and 3 distal screws (Fig. 26). During surgery, clinical and fluoroscopic control should be performed to check axis, rotation and length of the tibia.

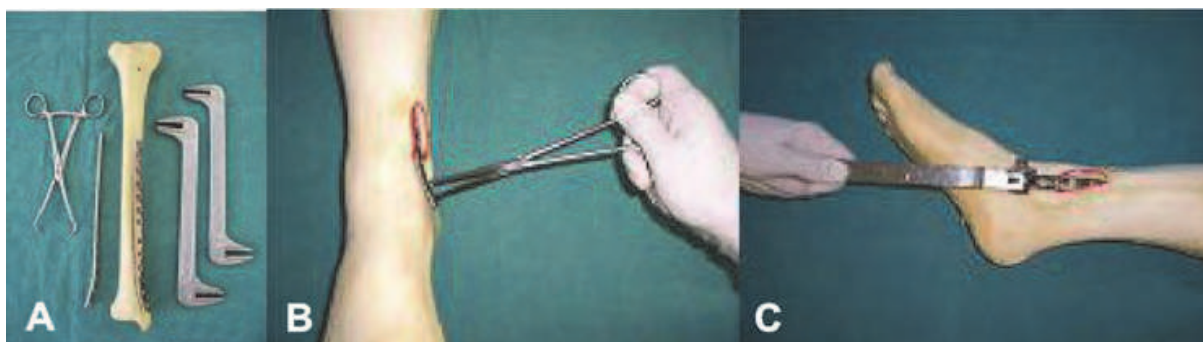


Fig. 25. (A) Devices for MIPO technique: reduction clamp and plate bent device (B) Plate pushing by a Kocher clamp or (C) With a condylar blade plate holder.

In 2006, we have published the preliminary results (Sirbu et al., 2006) using a medial approach and MIPO technique for unstable proximal and distal fractures of tibia. 22 fractures (2 A-type, 4 B-type and 16 C-type fractures/ AO) were investigated. Under clinic and fluoroscopic control for axis and rotation, the plate is inserted beneath the skin by a limited medial approach and fixed by screws. All fractures healed, within a mean time of 13 weeks (no bone grafting); there were no infections, nonunions, skins troubles or implant failures. 4 fractures healed with more than 5° of varus/valgus alignment, and 1 fracture healed with more than 10° recurvatum. All patients had a satisfactory knee and ankle range of motion. The conclusion was that this demanding technique represents a reasonable alternative to the standard methods of internal or external fixation in these fractures.

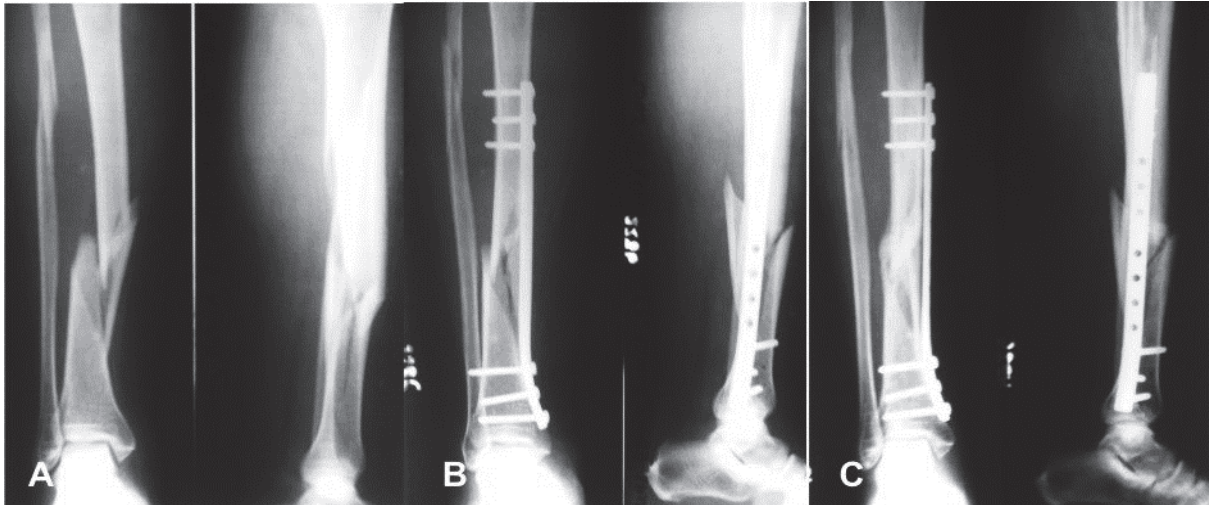


Fig. 26. (A-C). MIPO of distal tibia by medial approach with fracture healing at 4 months;

7. Conclusions

The results obtained by the authors in different services of trauma and orthopaedics showed that plates with angular stability represents an improvement of the internal fixation of the complex periarticular fracture of the long bones as well as an improvement of a percutaneous technique.

With a good knowledge of the operative technique and careful preoperative planning, these plates represent excellent and safe procedures for difficult articular fractures. Internal fixators can be expected to maintain, but not obtain fracture reduction, so care should be taken to insure a proper close reduction before insertion of the locked screws.

In the future, the real time photogrammetry and triangulation techniques by top-performance software will allow the trauma surgeon to obtain accurate images in order to reestablish the length, axis and rotation during minimally invasive techniques (Ip, 2006)

Close cooperation between orthopedic surgeon, biomechanics and robotics specialist, and the departments of cell biology and pathology will contribute to the creation of the ideal internal fixator and will represent the premises for experimental investigations required to elucidate the dynamic and coherent process of callus formation.

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Biomechanics in Applications

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During last couple of years there has been an increasing recognition that problems arising in biology or related to medicine really need a multidisciplinary approach. For this reason some special branches of both applied theoretical physics and mathematics have recently emerged such as biomechanics, mechanobiology, mathematical biology, biothermodynamics. The Biomechanics in Application is focusing on experimental praxis and clinical findings. The first section is devoted to Injury and clinical biomechanics including overview of the biomechanics of musculoskeletal injury, distraction osteogenesis in mandible, or consequences of drilling. The next section is on Spine biomechanics with biomechanical models for upper limb after spinal cord injury and an animal model looking at changes occurring as a consequence of spinal cord injury. Section Musculoskeletal Biomechanics includes the chapter which is devoted to dynamical stability of lumbo-pelvi-femoral complex which involves analysis of relationship among appropriate anatomical structures in this region. The fourth section is on Human and Animal Biomechanics with contributions from foot biomechanics and chewing rhythms in mammals, or adaptations of bats. The last section, Sport Biomechanics, is discussing various measurement techniques for assessment and analysis of movement and two applications in swimming.

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