The use of plates for internal fixation gains more and more importance and acceptance due to the introduction of new implants offering the possibility to lock the screw head with the plate. With this new plate generation, different fixation concepts can be considered and in addition the indication for plating is spread out to the diaphyseal segment of bone. For proper application of the implants—and to avoid technical or mechanical complications—a thorough understanding of the basic concepts of fixation, the bone biology and biomechanics, remains of outstanding importance.

Emanuel Gautier

Bridge plating

Refections useful for the adapted use of plates and screws in internal fixation

More or less all implant systems used in internal fixation consist of two main elements—a longitudinal element for the load transfer from one main fragment to the other and a transverse element to assure the coupling of the implant system to bone (Table 1). When comparing internal fixation with intramedullary nails or internal fixation with plates some major differences appear. Using an intramedullary nail for a diaphyseal fracture the mechanical concept is more or less independent from the fracture pattern—simple fracture, wedge fracture, comminuted fracture. In addition, the position of the nail, the length and diameter of the nail as well as the position of the locking bolts are more or less given and standardised by the local anatomy of the broken bone segment as well as the implant design.

In contrast to nailing, plating offers two different fixation concepts—splinting and interfragmentary compression. Comminuted fractures are best treated using a splinting technique, because local bone and soft tissue devascularization can be minimized; while in simple fractures the application of interfragmentary compression can be considered as a stabilization tool.

Plate position is chosen mainly according to the local anatomy and the surgical approach chosen. But, depending on mechanical demands, the plate position can be altered (tension side, compression side). In addition, the length of the plate itself, the number and the relative position of screws which need to be inserted, as well as the type of screws (standard cortical screws or locking head screws, mono- or bicortical screws, self drilling or self tapping screws) remain under debate. Thus, a lot of additional decisions have to be taken by the surgeon when planning and performing plate osteosynthesis. It is also evident that plating is intellectually and technically much more demanding than nailing (Table 2).

The three following main factors influence the stability of the fixation and the loading conditions of the plate bone construct: The overall length of the plate, the overspan length of the plate, and the number, position and design of the screws.

Length of the plate

Utilizing the newer minimally invasive techniques of indirect reduction, subcutaneous or submuscular plate insertion and splinting as a stabilization concept, the plate length can be chosen to be very long without the need of additional soft tissue section and devascularization.

Theoretically the plate can equal the whole length of the broken bone. But, at least the minimal length of the internal plate can be determined by means of the two factors: The plate span width and the plate screw density. Plate span width is defined as the quotient of the plate length and overall fracture length. Empirically we find that the plate length should be two to three times higher than the overall fracture length in comminuted fractures and eight to ten times higher in simple fractures. The second factor is the
Plate screw density which is the quotient formed by the number of screws inserted and the total number of plate holes. Empirically we recommend values below 0.5, indicating that less than half of the plate holes are occupied by screws (*Fig 1a–c*).

Number of screws

From the mechanical point of view, two screws (monocortical or bicortical) on each main fragment, is the minimum number of screws needed to keep the plate bone construction stable (*Fig 2a–c*). Unfortunately, such a construction will fail if one screw breaks due to overload or when the interface between bone cortex and screw is threatened due to bone resorption with subsequent screw loosening. Thus, for safety reasons we recommend a minimum of three screws in each the proximal and the distal main fragment.

Adjusting the plate screw density to a maximum value of 0.5 the plate length should not be chosen below a 12-hole plate for treatment of a diaphyseal fracture. But, to increase the leverage of the screws the use of a 14- to 22-hole plate would even be better.

Effect of plate length on screw loading

The length of the plate and the position of the screws modify the loading conditions of the screws. Increasing the length of the plate decreases the pullout force acting on the screw due to an improvement of the active lever arm of each screw (*Fig 3a–b*). This argument points to the use of long plates (nearly as long as the bone itself).
Fig 2a–c Minimal requirements for internal fixation using plates.
Two screws to couple each main fragment to the plate is sufficient from the mechanical point of view. But, the construct becomes to be unstable if one screw fails due to fatigue failure or due to resorption at the bone-screw interface with subsequent screw loosening. Thus, for safety reasons 3 screws for each main fragment can be recommended.

Example of plate fixation of a humeral shaft fracture using a minimal number of screws showing the undisturbed course of bone healing—postoperative radiograph (a), situation at 3 months (b), and 6 months (c).

Fig 3a–b Influence of lever arm on pull out of screws.
Using a long plate improves the lever arm of the screws. This leads to a low pull out force acting on each screw. A short plate creates higher pull out of the screw (a) compared with a long plate creating lower pull out of the screws (b).

Fig 4a–b Decreasing the implant deformation and strain with adaptation of screw positioning.
Bending the plate over a short segment increases the strain within the plate (a). To decrease the relative plate deformation the distance between the innermost screws should be increased (b). This distributes the implant deformation over a longer distance and reduces the strain within the implant—as long as the overall plate angulation remains unchanged due to a distance limitation of the opposite bone cortex.

Fig 5a–c Submuscular splinting of a simple femoral shaft fracture.
Spreading out the two innermost screws leads to a sound strain distribution within the implant and a sound bone healing documented by radiographs taken postoperatively (a) at 4 months and 3 years (b and c).

Fig 6a–c In the case of a comminuted diaphyseal fracture spreading out the innermost screws is dictated by the fracture pattern leading to low implant strain under the prerequisite that the overall deformation and angulation is limited by partial contact of intercalated fragments at the opposite cortex (a). In case of no distance limitation plate angulation is not hindered (b) and can equal the critical strain values seen in the schematic drawing with splinting a simple fracture by means of a plate leaving a small gap between the main fragments and positioning the screw as close as possible to the fracture (c).

Fig 7a–d Working length of the screws.
The screw threads need to be engaged in the bone cortex over a certain distance to assure sound anchorage of the plate. A normal cortex is sufficiently thick to allow good anchorage. Even a monocortical screw can withstand the torque potentially acting between two fragments and thus loading the screw thread bone interface (a, b). In case of osteoporosis the cortex is thin reducing the working length of the screw (c). In this situation even low interfragmental torque can damage the screw bone interface with subsequent loosening and instability (d). Thus in osteoporosis it is mandatory to use bicortical screws with improvement of the working length of he screws (e).
Effect of plate length and screw position on plate loading

When using the concept of interfragmentary compression in a simple fracture pattern, load sharing conditions between plate and bone are present and in this way the screws in the middle of the plate can be inserted as close as possible to the fracture. When using the concept of splinting in a simple fracture pattern, the middle plate segment is bent over a short distance enhancing the local strain within the implant. To avoid high implant strain, the innermost screws should be spread apart, which increases the length of the plate segment bending, thus decreasing the implant strain. This protects the plate against fatigue failure (Fig 4a–b). Figures 5a–c show a clinical case of a femoral shaft fracture stabilized according to the previously described principles.

In the case of comminuted diaphyseal fractures, the plate spans over the fracture like a non gliding splint. A longer distance between the two screws adjacent to the fracture is dictated on the one hand, by the fracture pattern itself and on the other hand, for mechanical reasons, by the spreading out of the innermost screws thus decreasing the implant loading—but only when there is a distance limitation on the opposite cortex. Without distance limitation the deformation of each plate segment in the middle depends on the acting bending moment. Each plate segment is deformed according to the external loading condition—thus, the overall deformation is much higher and the implant strain can become high and critical, as in the situation where it is bridging a small gap with a short plate segment between the two innermost screws (Fig 6a–c).

Appropriate screw selection

The selection of the screws is dependent on the bone quality, cortical thickness, and external loading conditions of the bone segment. We have the choice between monocortical and bicortical screws, self tapping and self drilling screws, as well as standard and locking head screws. The use of locking head screws has advantages where bad bone quality is found as screw loading is no longer only pure pullout but also bending, altering the loading condition at the interface bone-screw thread. The choice between self tapping and self drilling screws should be made according to the anatomy of the segment. Self tapping screws can be used as bicortical screws, whereas self drilling screws should exclusively be used as monocortical screws because the stick out length for anchoring in the opposite cortex is too long which increases possible harm to the soft tissues on the opposite cortex. In very osteoporotic bones, which typically present a thin cortex or a bone segment under high torsional loading, the use of bicortical screws is mandatory to enhance the working length of the screws and to avoid torsional displacement of the fractured fragments (Fig 7a–e).

Effects of the internal fixator concept on bone healing

Using plates as internal fixators with locking head screws has the advantage that a certain distance is present under the implant. This enables the cortex underneath the plate to form bone callus allowing faster and stronger bone healing.

Take home messages for plating:

• Splinting is a sound stabilization principle for fixation of comminuted fractures.
• Splinting can be used for stabilization of simple fractures—when, on the one hand, a long plate is used to improve the lever arm of each screw, decreasing the screw pullout and, on the other hand, the two innermost screws are spread apart leaving at least two to three plate holes unoccupied at the fracture site to decrease plate loading.
• Interfragmentary compression remains a sound stabilization tool for fixation of simple fractures under the prerequisite of careful soft tissue section and handling.
• The use of locking head screws is advantageous from the biological point of view. Such an internal fixator does not compress the periosteum and thus reduces the amount of avascularity of the bone cortex adjacent to the plate. In addition callus formation is possible in the gap between plate and bone cortex.
• Monocortical screws should only be used in case of good bone quality and sufficient cortical thickness, as well as in bone segment not loaded with high torque.
• Self drilling screws are exclusively used as monocortical screws in the diaphyseal bone segment to avoid harm to the soft tissue due to the long sticking out length of a bicortical self drilling screw.

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