Evolution of AO Fracture Treatment Part 1: the Internal Fixator

Vývoj léčení zlomenin podle AO. Část 1: vnitřní fixatér

S. M. PERREN[1], A. FERNANDEZ DELL'OCA[2], P. REGAZZONI[3]

[1] Davos, Switzerland
[2] Hospital Britanico Montevideo, Uruguay
[3] Lugano Soragno, Switzerland

Introduction

Surgical fracture treatment has undergone an extensive evolution in the past decades. In the early days achieving solid healing in anatomically reduced position was the primary and nearly exclusive goal of fracture treatment. Since mainly Lambotte, Danis and Müller in Europe the focus of surgical fracture treatment shifted to achieving early **recovery of the function** of the injured limb with safe healing. Considering the shortcomings of the early fracture treatment helps understanding the evolution of surgical fracture treatment. The evolution of the biomechanical and biological principles of AO plate fixation are discussed as a model.

Shortcomings of early ORIF in need of solutions

Hansmann 1886 (8, 21) lends itself well for discussing the shortcomings of early surgical fracture fixation (Fig. 1). The reduced short oblique fracture was bridged with a plate fixed with screws to the two main fragments. The dimensions and material of the **thin plate** were not optimal to withstand the loading of functional after treatment. The overall shape of the screws was like **woodscrews** of conical overall shape of the thread. In contrast to wood, which is tough and flexibly deformable, the bone cortex is brittle. Bone tolerates very small deformation before it fractures. Thus, conical screws would either destroy the thread when forced to press the plate to the bone or – avoiding the damage of the bone thread – the screw would not press the plate to the bone surface. Pressure[1] is a requirement for solid coupling based on **friction** between bone and plate. The flat under-surface of the screw heads indicates that such pressure was the intended mechanism of fixation. The mode of action of such a fixation relies on producing friction. The friction very rigidly resists, within limits, shear displacement. The limits are set by pressure and the coefficient of friction. The transcutaneous extensions as used by Hansmann with their inherent risk of infection is not discussed here.

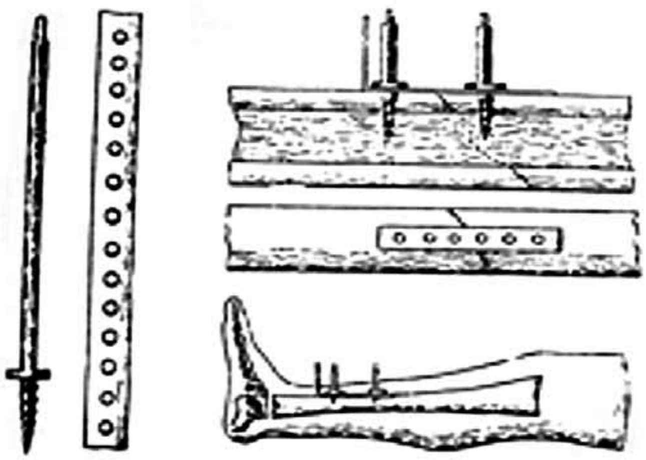

Fig. 1. Unicortical, conical woodscrew type fixation (Hansmann 1886).

Shifting priorities of surgical fracture treatment

An essential step in the evolution of fracture treatment was the shift of the goal of treatment from prioritizing healing to prioritizing early regaining **function:** *"the chief aim in fracture treatment is the return of the injured limb to full activity"* (12). This shift was a reaction to the observation of dystrophy from immobilization of soft tissues and articulations. The function of the implants was now to stabilize the fracture while allowing early and full recovery of function of the soft tissues. The plate designed by Danis was strong and the screws efficient. The Danis screws showed a cylindrical outline of the thread with asymmetric thread elements, which offered perpendicular surfaces carrying the axial force exerted by the screw (1).

To prevent fracture mobility (i.e. relative displacement of the fracture fragments) the Danis plate took advantage of a built-in worm screw that allowed to **compress** the

[1] The clinically used term "pressure" is used for force pressing two elements together

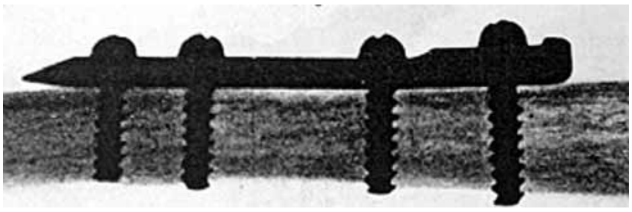

Fig. 2. Solid plate, cylindrical outline of screw thread and asymmetrical thread elements (Danis R. 1949). The screws are loose, the plate does not share load.

fracture along the long axis of the bone (Fig. 2). This was a method for stabilizing mainly transverse components of fractures. Müller et al. defined the goal of surgical fracture treatment as allowing healing in mechanically neutral conditions to allow immediate recovery of function of the soft tissues. The plate was now considered to be a component in a structure that allowed to compress the different fracture surfaces.

M.E. Muller together with R. Mathys developed a complete **set** of implants and corresponding instruments that allowed to realize fixation according to the principles of compression by lag screws and protecting plates resulting in what was called "**primary**", callus free fracture healing (18). The appearance of callus was interpreted as a sign of failure to achieve so-called "absolute stability". To minimize the risk of refracture after implant removal the implants were left in place for at least two years. Müllers vision was an integrated effort including:

- **documentation** of success and failure defining problems with the new technology,
- **research** providing understanding and innovation solving problems,
- hands-on **teaching** to enable surgeons safely applying demanding techniques.

The integration of all these elements was the basis of the worldwide success of the AO study group braking the limits of genial and skilled single pioneers such as the techniques developed by Lambotte and Danis that were ahead of time but unfortunately missed general acceptance due to lack of the mentioned integration.

Improving biology as a next step

AO research first addressed the obvious contradiction between the then generally accepted term "pressure necrosis" and the application of **compression** to securely stabilize fractures. It could be shown that, if compression did not mechanically destroy bone, bone would tolerate even high amounts of static compression without deleterious effect (16, 17). Beside keeping fracture fragments from moving, in relation to each other, the static compression had no effect on fracture healing. Objectionable **loosening** of implants was explained as induced by micromotion at the interface bone to implant (13). The fact that minute amounts of mobility[2] could induce implant loosening while large amount of mobility were tolerated in for instance spontaneous fracture healing

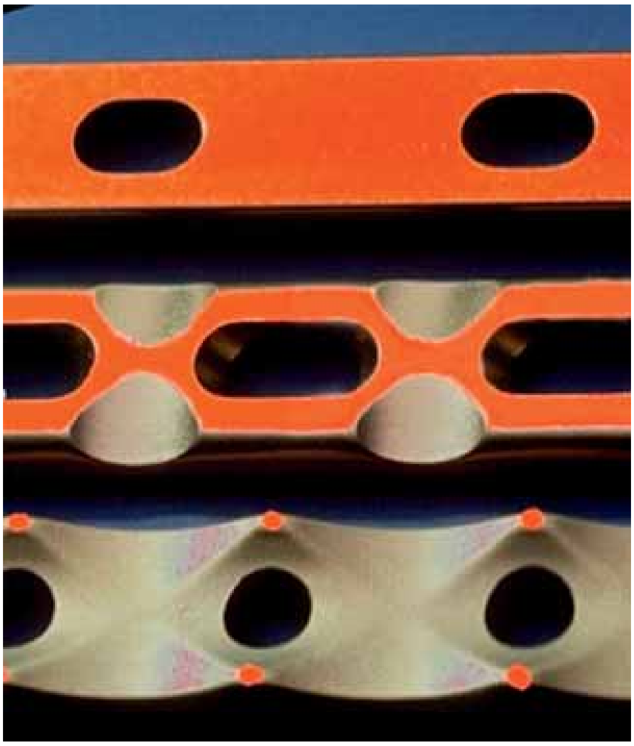

Fig. 3. Minimizing contact damage.
- DCP (16) no undercuts,
- LC-DCP undercuts,
- PC-Fix only point contact

were explained based on cell deformation (strain) replacing the insufficient expression of fracture mobility (strain theory) (15). Observing that a rigidly stabilized fracture healed without callus and that internal remodelling of primary healing was a side effect of necrosis remodelling, research promoted a fracture stabilization which maintaining the goals of early function allowed to induce the repair process (13). Thus, a more **flexible** fixation was tested and proposed. The implant, such as the plate and screw, would no longer function producing compressive stability but rather act as a splint reducing but not abolishing mobility of fracture; Keeping the balance between inducing repair and still allowing functional after treatment. Thus, induction of repair was maintained. The optimal degree of fracture mobility to induce and still allow tissue differentiation was defined as a bandwidth of tissue deformation (**strain**) (14). The terms of fracture mobility and of stability of fixation were replaced by "strain" defining specific amount of tissue deformation.

An essential progress based on research was enabled when the **loss** of bone in the segment in contact with a bridging implant was no longer explained as "stress protection" but as temporary porosity in a process of remodelling of the contact necrosis (6). When intensified by, for instance infection, the pores could converge and

[2] The term mobility refers to relative displacement at interfaces such as between fragments of the fracture.

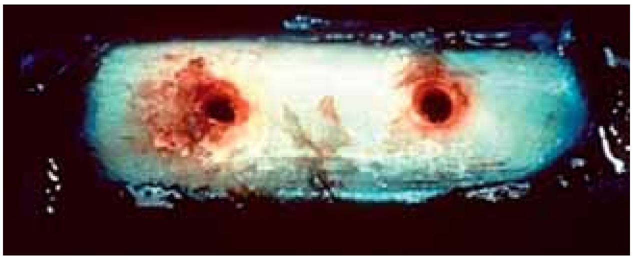

Fig. 4. Contact damage to blood supply. Full contact, large avascular area of contact (18).

Fig. 5. Contact damage to blood supply. Undercut contact reduced avascular area of contact (Fig. 8), (18).

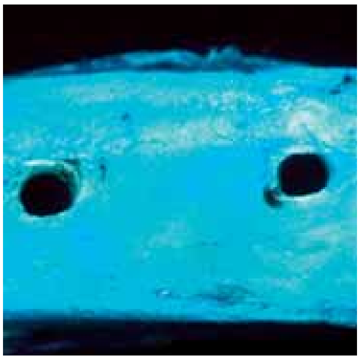

Fig. 6. Contact damage to supply. No contact Elevated plate or point contact PC-Fix, the plated segment is well vascularized (17).

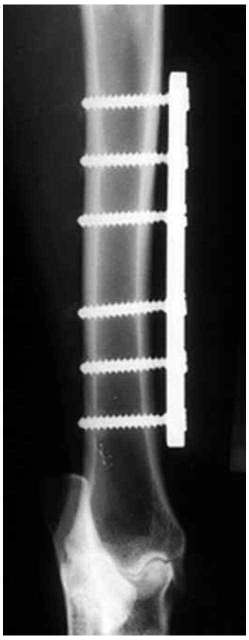

Fig. 7. Elevated plate functioning as internal fixator.

produce a sequester. The consequence of this new understanding was to minimize the implant contact (Fig. 3 – Fig. 7). The statement that undercutting does not reduce the contact (4) is understood as depending on the relation between radius of under surface of the plate in relation to the one of the bone surface (Fig. 8). Undercut plates and elevated plates were developed and tested. The PC-Fix with its locked screws and minimal point contact proved the concept. The function of the

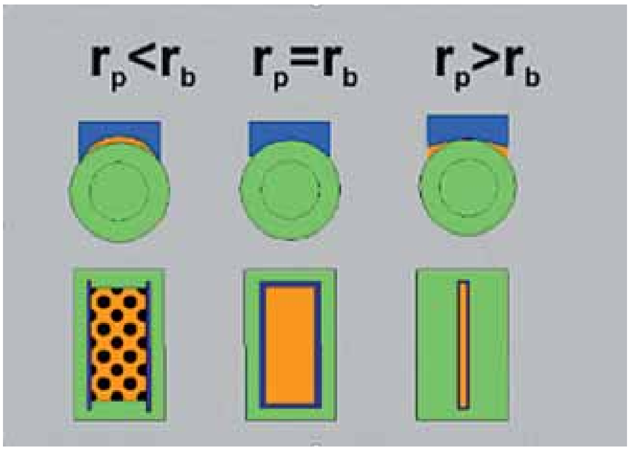

Fig. 8. Contact depending on relation of radii of plate and bone.
Left: Plate radius smaller than bone radius, large cross section cut off.
Middle: equal radii, large area contact damage, rare situation.
Right: Plate radius lager, contact of a small band, no effect of undercut.

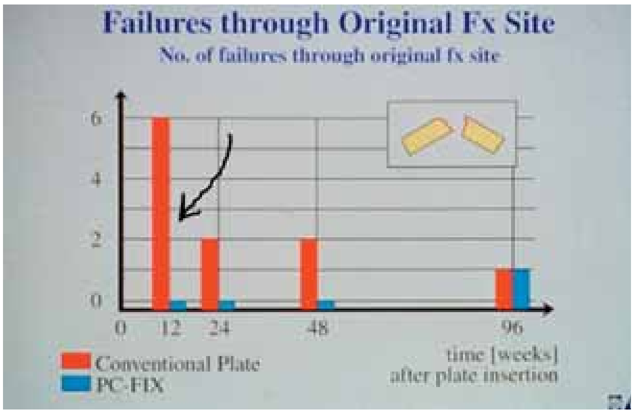

Fig. 9. Fracture healing strength, comparison of conventional compression plate and PC-Fix. The different speed of reaching solid healing is impressive as the PC-Fix reaches solid healing in 12 weeks (19).

locked screw is best understood as providing the function of an internal fixator. The extensive and closely monitored clinical studies of the **PC-Fix** provided impressive results, such as solid healing in 12 weeks (Fig. 9), but the step of evolution was too early and too large to be accepted by leading surgeons and with-it industry (3, 7). The principle of locked screws was then applied together with the widely accepted DCP principle to the Locked Compression Plate (**LCP**) with its "combi holes". Parallel to the mentioned development the clinical development caring for biology resulted in the minimally invasive plate osteosynthesis (MIPO). The use of titanium as implant material avoided allergenicity to nickel and chromium in the steel but its excellent tissue tolerance did not only improve infection resistance but allowed bone to grow into the thread between screw head under surface and plate resulting in unwanted contribution to jamming at screw removal.

Improving locked screws

To allow elevation of the plate from the bone surface the screw needed to be modified in a way that held the plate elevated and resisted functional load. First the screw head under surface was a steep cone (Morse cone) that produces a strong radial press fit when the screw was driven home even lightly (PC-Fix). Later the cone angle was less steep and threaded with conical overall shape (Less Invasive Stabilization System LISS) (5). Such coupling between plate and screw was used together with part of the DCP design as "combi hole" for the LCP.

The **LCP** combi hole is a combination of conventional fixed angle locked screw and the compression component of the spherical principle of the DCP (5, 20). The LCP allows three different applciations of plate screws (Fig. 10–Fig. 12):

- a locked screw applied in perfectly aligned position (ICUC ID 22-OB-019 image 67 of 105) (Fig. 10),
- a conventional screw for compression (ICUC ID 22-GA-955 image 52- 56) (Fig. 11) and
- a conventinonal screw in neutral position for pulling fragments to the plate), a mechanical advantage and a biological shortcoming (Fig. 12). (ICUC ID 42-SI-754 image 55–57).

The disadvantage of the conical fit between screw head and plate was that it served the purpose only when applied perfectly aligned with respect to the long axis of the screw hole ("Fixed Angle Locking FAL"). Outside the limit of a few degrees from this position it would lose tight coupling (10, 11). Therefore, a spherical screw under-surface was used ("variable angle locking VAL") that maintained locking in tilted application Comparative testing of these designs by Lenz revealed that the variable locking held firmly up to 15 degrees angulation while the fixed angle screw lost its locking when inserted at an angulation of only a few degrees off perfect alignment (9, 10). This is relevant because even experienced surgeons trying to insert screws perfectly aligned were deviating more than the critical 2° (2).

Outlook

The internal splinting of fractures has reached a, safe and efficient level. In internal fracture treatment, the reduction of the fracture is demanding and time consuming while the stabilization is mostly straight forward. Improving reduction technology seems to be a priority item. Another priority item is preventing occurrence and/or improving treatment of complications. In this respect, the retrospective analysis such as provided by the ICUC concept may provide important information and deserves attention.

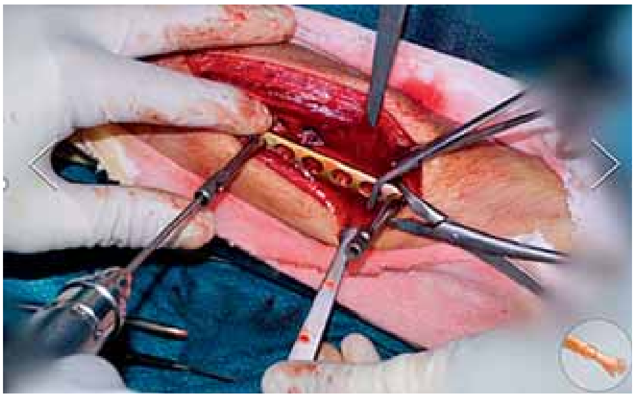

Fig. 10. Application of a locked screw in perfectly aligned position (ICUC ID 22-OB-019 image 67 of 105).

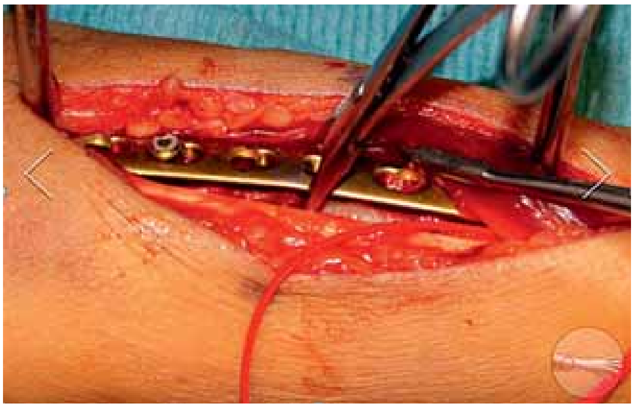

Fig. 11. Application of a compression screw (ICUC ID 22-GA-955 image 53).

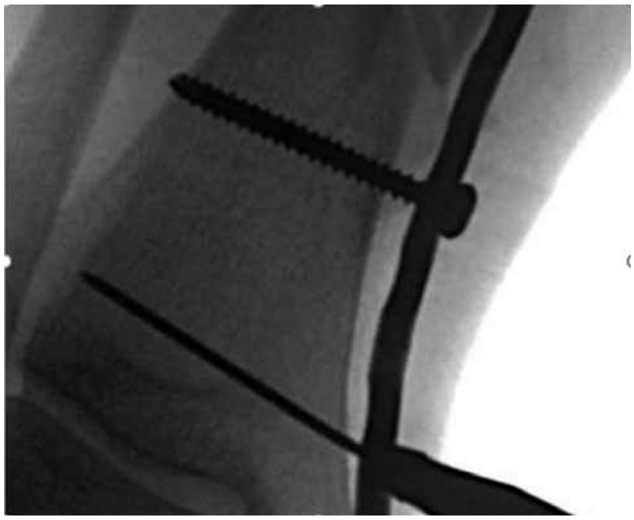

Fig. 12. Application of a conven-tinonal screw in neutral position for pulling fragments to the plate (ICUC ID 42-SI-754 image 56).

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Corresponding author:
Prof. Dr. med. Stephan M. Perren, founding member
and scientific advisor AO Foundation
Dischmastr. 22
CH-7260 Davos, Switzerland
E-mail: sperren1@bluewin.ch