Clinical relevance of mechano-biological foundations of implant coupling to bone

Towards optimal control of interface conditions through knowledge extraction based on ICUC® cases

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Controlling the biomechanical conditions of the implant to bone interface is key to clinical success when it based on the understanding of bone reaction.

The function of implants in fracture treatment depends on coupling between bone and implant. On the one hand loss of coupling between implant and bone compromises or abolishes the stabilizing function of the implant. Such loosening is most frequently the result of bone surface resorption at the interface. On the other hand, maintained tight coupling over years would, according to Wolff's law, cause unfavorable bone loss.

Initially locked screws were found to be loose [1] at plate removal in cases of the ICUC® App (Fig. 1). The question was: Under what conditions do the screws provide or release solid coupling between bone and plate [2]?

Several components may contribute to loosening of bone screws:

- Unlocking of the screw to plate connection
- Bone resorption at the interface implant-to-bone
- Local mechanical overload resulting in destruction of the bony thread
- Overload resulting in failure of the implant

In the following figures and animation, we focus on biomechanical conditions, which induce the biological loosening.

Figures 2 to 5 give an overview of the critical interfaces of implants used in fracture treatment. Based on earlier clinical and experimental observations, it is obvious that intermittent mechanical gapping of the implant to bone interface induces bone surface resorption as observed in the clinical sample case (Fig. 1) *(3)*.

The animation (Fig. 6) is an analysis of the balance of forces at the interface between static compressive preload and dynamic traction resulting from function of the limb. To begin with, the interface is in solidly preloaded contact. With increasing functional traction the preload at the interface decreases until traction exceeds compression. Whenever the traction exceeds the compressive preload the interface opens intermittently and bone surface reabsorption is induced. The latter results in gross loss of coupling. When applying this observation to clinical fracture treatment, it is important to understand that within the same fragment screws act in parallel that is coupling is lost only if all the screws in the same bone fragment are loose. When considering the coupling between fragments, coupling acts serially, that is, if one of the components gives way the overall stability is lost.

Summary: Coupling enables the stabilizing function of implants used for fracture treatment (and of endo-prosthesis). Based on knowledge from clinical cases like ICUC ID:42-SI *(1)* the biomechanical foundations of implant loosening are discussed. An animation explains the mechanical conditions resulting in biological loosening of implants.

1 The data obtained will be reported in a next ICUC one page reports.

2 This long-term effect is different from what was erroneously called "stress protection" appearing in a few weeks and being a reaction to bone necrosis.

Fig. 1: **Clinical case of screw loosening.** The picture #113 out of 226 of the ICUC® case ID:42-SI-113 shows, at 74 weeks after open reduction and internal fixation of a torsional tibia fracture, screws with different coupling. When the screws were removed measuring the torque required in the distal fragment both screws were found to be loose with loss if coupling (red circle) while both screw in the proximal fragment were solidly coupled (green and yellow circles).

Different interfaces conditions to be considered are listed in the following overviews

References: Tight frictional coupling Interfaces

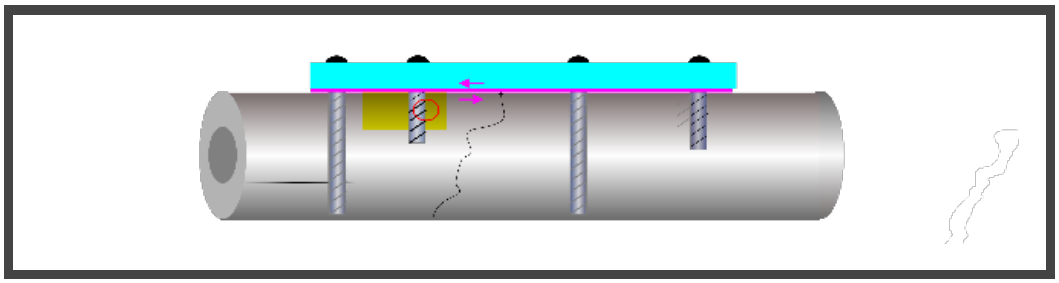

Fig. 2: Screw to bone interface [3]. The fracture is in close contact and shares load. The function of the screw to bone interface is producing axial force, which presses the plate to bone and creates friction. The plate to bone friction (magenta) provides a very tight coupling between plate and bone.

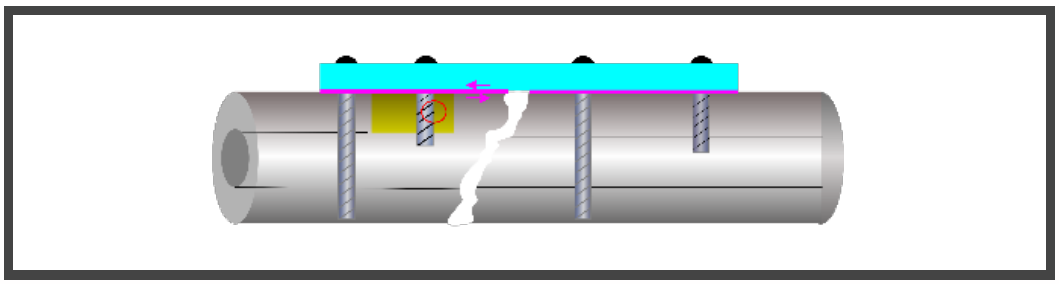

Fig. 3: : Same components as in Fig. 2 but with open fracture gap, Therefore, full functional load is carried by the implants. Tight frictional coupling of plate to bone due to friction produced by axial force of screws.

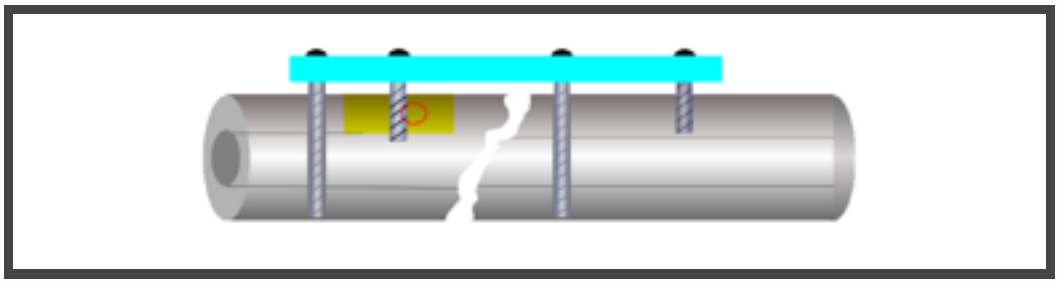

Fig. 4: Interface condition of an elevated and locked plate. The fracture gap is open. While the screw to bone coupling is tight the overall coupling between the fragments is somewhat flexible with improved callus induction *(2)*. The elevated plate prevents contact damage to blood supply of bone *(4)*.

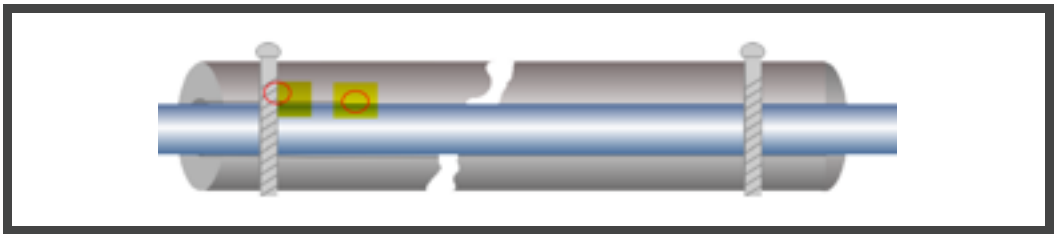

Fig. 5: Two interfaces of a locked medullary nail. The radial preload of the nail is small and produces usually a frictional component, which is too small to prevent axial and torsional displacement. Thus, the screw to bone interface carries practically the full functional load acting perpendicularly to the long axis of the screw.

3 The example with the red circle applies to all screw to bone interfaces.

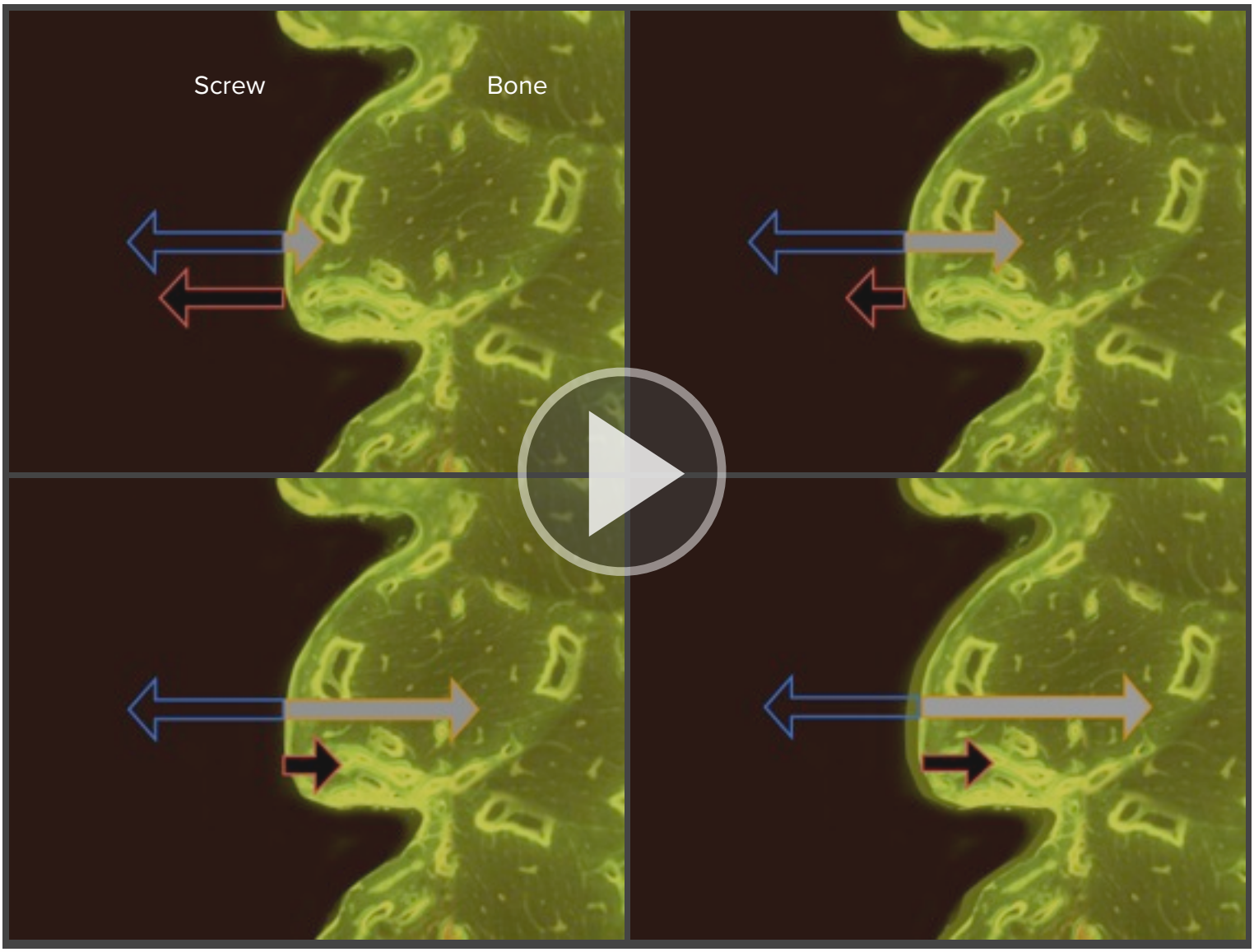

Fig. 6: **Animation** visualizing the dynamic balance of compressive preload vs. functional traction resulting in gapping of the interface.

Further Readings

1. www.icuc.net

2. Pietro Regazzoni, Peter V. Giannoudis, Simon Lambert, Alberto Fernandez, Stephan M. Perren
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3. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology.
J Bone Joint Surg Br. 2002 Nov;84(8):1093-110.

4. Gautier E, Sommer C.
Guidelines for the clinical application of the LCP.
Injury. 2003 Nov;34 Suppl. 63-76.