“Balanced fixation” in the surgical treatment of long bone fractures

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Problem: Balance in internal fixation concerns first of all the balance between efforts to stabilize a fracture and the additional tissue trauma they will cause. That is, if the surgeon insists on or needs to achieve a very stable fixation (for instance by applying lag screws inserted from a direction more or less out of the surgical approach field), he may pay a high price in damage to the blood supply (Fig. 1). This aspect will be dealt with in a subsequent “ICUC one page”. Here we address biomechanical basics first and, clinical applications to improve stabilization second.

Balancing serves to optimize fixation. This applies to balancing the strength of the components because the weakest element in the chain (of fixation) limits the overall strength (Fig. 2, 3, 4). It also applies to balancing stiffness (Fig. 4 and 5). Balancing fixation allows the surgeon to improve fracture stability and with it the safety (that is, the least number of complications) and performance (that is, the best possible outcome) of internal fixation. Therefore, it matters to focus on understanding the basic aspects and clinical application of “balanced fixation” (Fig. 6 – 13: 12-SI-087).

Balance and balancing is frequently dealt with in literature with respect to many concepts – of resource management, clinical risk management etc., but to our knowledge, the issue of balancing strength and/or stiffness has not been addressed in fracture management literature so far.

Balanced strength

Surgical stabilization connects fracture fragments solidly providing strength to carry load without failure. For this purpose, the implant needs to be solidly fixed to both main fragments. Whether the fracture surfaces are intrinsically stable (that is, there is optimal interdigitation of the surfaces) or not (a multifragmentary fracture) when the load applied to the bone increases, the interconnected chain of bone-fixation-bone will give way first at its weakest link. To prevent premature failure balanced strength between the two couplings and the implants is an important goal (Fig. 2).

Balanced stiffness

Besides balancing strength, balancing stiffness needs consideration. As the stiffness of the different components (e.g. locked screw / plate / locked screw) simply add up (Fig. 5) there is no stringent goal to keep the different stiffnesses equal. However, if the stiffness of one component is very low this component would undergo or sustain the most deformation and may therefore promote failure.

Special aspects

The following aspects require consideration:

- The effect of stiffness of the implant is obvious and depends on the material stiffness and structural stiffness (dimensions). The effect of material stiffness is comparably small when compared to the effect of dimensions, which may increase stiffness to the third power of the critical dimension. For instance, a longer plate will allow larger spacing of the screws and will resist translational deformation better than a shorter plate for the same fracture pattern, but it will not necessarily resist torsional deformation: the resistance to torque (and therefore shear displacement) is more related to the fracture pattern itself (this is the subject of another ICUC One Page).
- The effect of **coupling** is more complex
  - When, for example, a plate is kept elevated with locked screws (that is, it is not in contact with the bone surface), the bending stiffness of the screws and their leverage becomes more important. Stiffness of coupling decreases as the magnitude of elevation from the bone surface increases, and as the screw-free span across the fracture zone increases.
  - When screws anchor in both cortices the coupling with respect to tilting under torque load is much larger than coupling with mono-cortical screws* (which has a small lever arm of only single cortical thickness). The pullout force of bi-cortical screws is just less than twice the monocortical pull-out force due to the cross-sectional flexibility of the bone and consequent sequential failure.
  - When the under surface of a plate is pressed onto the bone the resulting friction may produce an extremely stiff coupling at the expense of harming bone biology.

* Beside screws anchored in one cortex only and screws anchored with the thread in both cortices there are self drilling screws whose thread only makes contact with one (near) cortex but whose tip is solidly jammed into the opposite cortex. The latter screws behave on pullout like monocortical screws but are like bicortical screws in respect to torque load (pseudo-mono-cortical screw).

Summary
The anchorage (coupling) of a bridging implant needs to be "balanced" to avoid failure of the weakest element in a serially connected chain. Beside the quality of screw anchorage in bone the spread (leverage) of the screws requires consideration. At first glance, the balance of strength seems to be more important than the balance of stiffness but both effects need careful consideration.

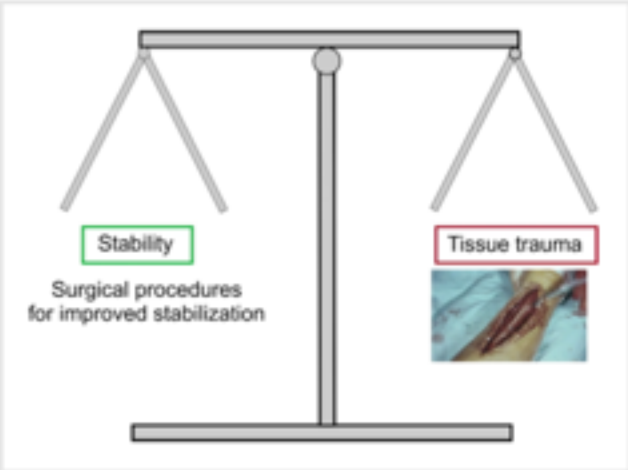

Fig. 1 Example of mechanical vs. biological balance. *When the surgeon insists on or is forced to apply advanced stabilization the biology suffers. To find the right balance is a difficult but important issue. This issue is mentioned here for clarification, but will be treated at length in a future ICUC One Page*

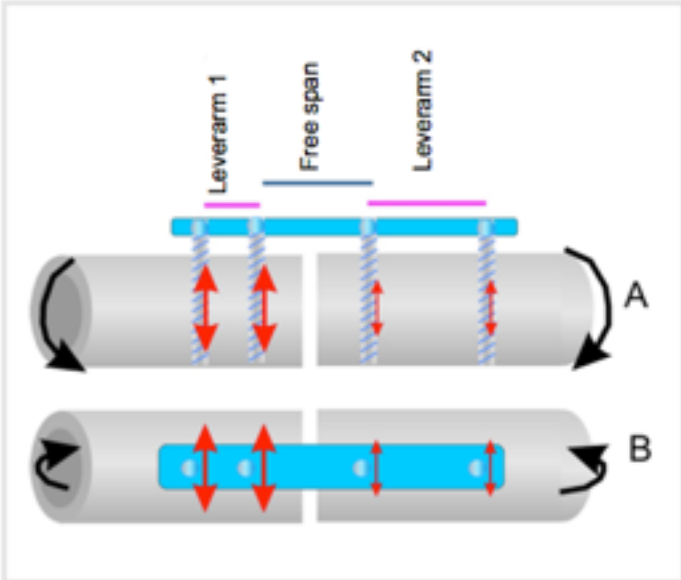

Fig. 2 The leverage of the screws (mono- or bicortical) is very different in the two main fragments shown. *Here simple bending loads applied in and orthogonal to the plane of the fixation screws around the small (A) and flat (B) surface of the plate are assumed. Under axial torque the situation is more complex and mono- vs. bicortical screws behave differently. The red arrows show the forces acting for the same overall bending load: the load sustained by the two screws close together in the left fragment is far greater than the load sustained by the screws in the right fragment: failure of fixation coupling is more likely in the left fragment for the same bone quality (strength), Figure 3.*

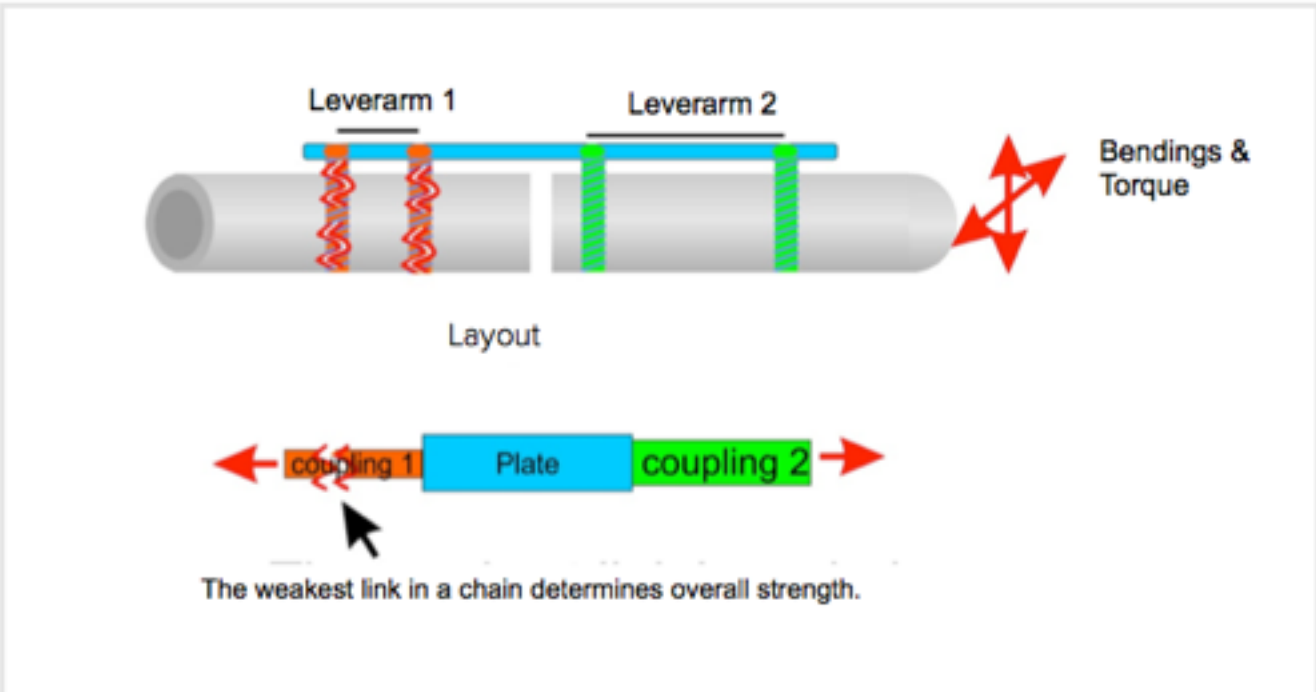

Fig. 3 The strength of a structure is determined by the weakest link in the chain. *Here the screws in the left main fragment will strip while the screws in the right fragment resist without stripping. Therefore, in respect to strength the issue of balancing an internal fixation is important. Once again, the leverage regarding bending in two planes is similar while torque is different.*

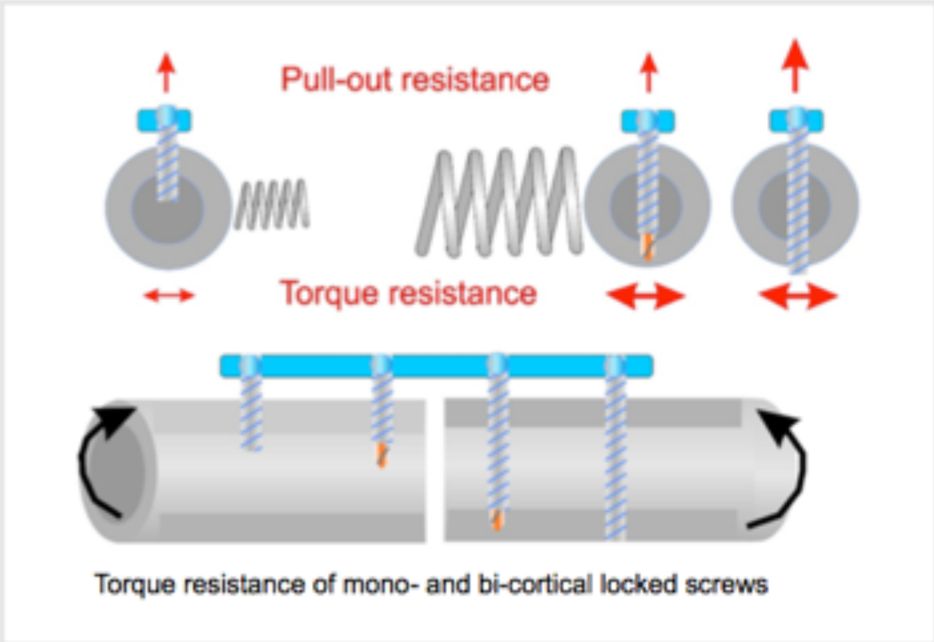

Fig. 4 Leverage of mono- vs. bicortical screws under axial torque load. *The resistance to torque of bicortical screws is much larger because the lever arm of the monocortical screw is only as large as the cortical thickness. The (self-drilling) screws that engage without thread in the remote cortex behave in respect to axial torque loading of the construct in a similar way to the bicortical screws (pseudo-monocortical screws). In respect to bending load the pull out strength of the pseudo-mono-cortical screws is similar to the mono-cortical screws, that is somewhat more than half of the bicortical screws.*

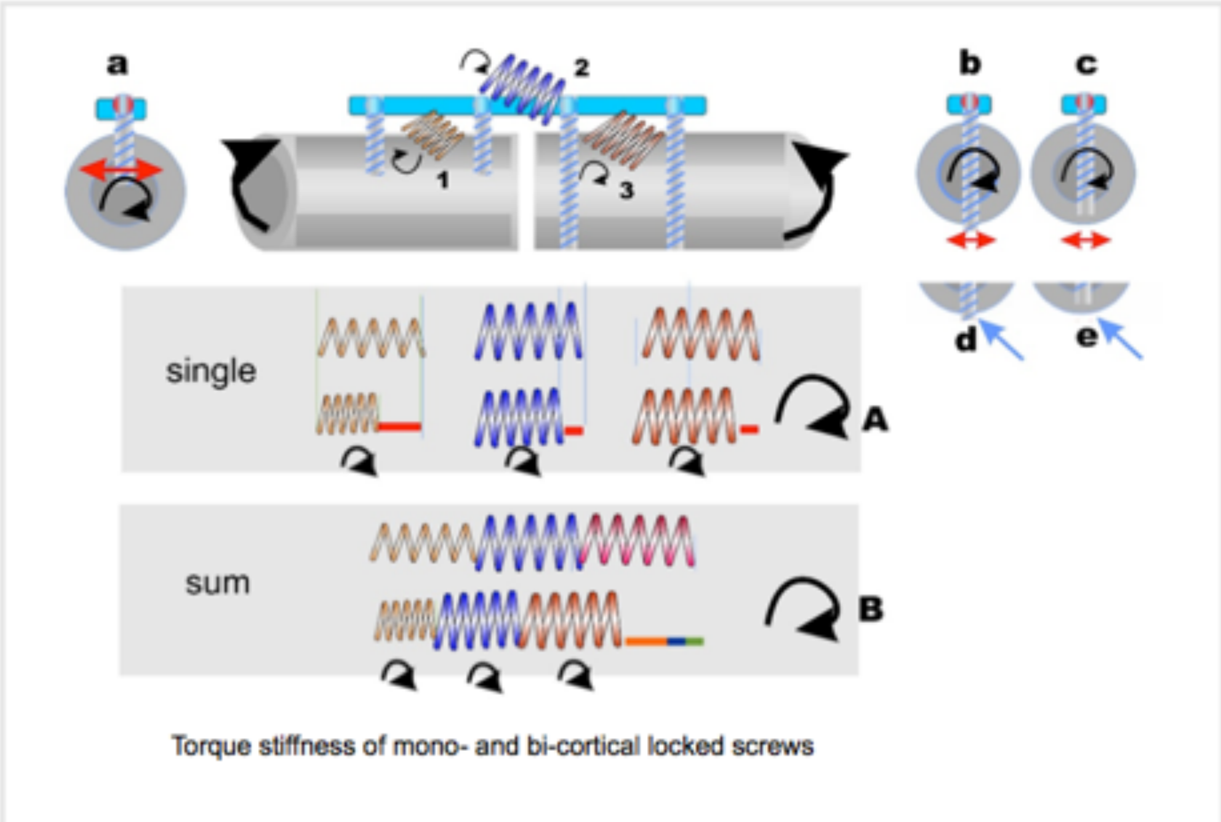

Fig. 5 Torque stiffness of mono- bi- and pseudo-mono-cortical screws. *The torque stiffness is represented by oblique springs (1, 2,3). The row (A) shows individual deformation (same load, different stiffness). The lower row (B) shows the sum of the deformations. Balancing stiffness is less important than balancing strength. The row (a,b,c) shows for the same torque load the contact forces perpendicular to the screw axis. Here the bi-cortical (b) and the pseudo-monocortical (c) screws behave the same.*

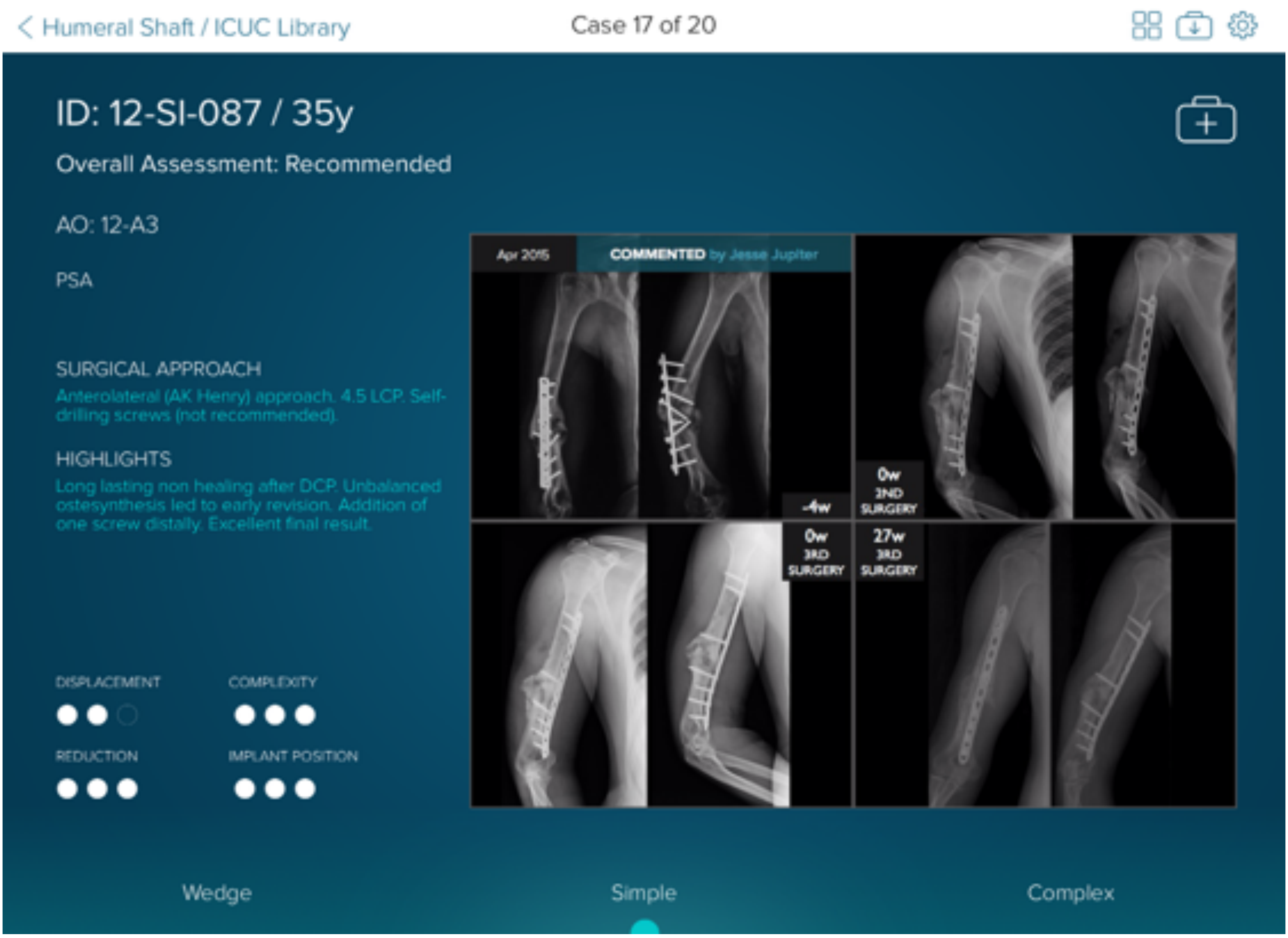

***Fig. 6* Case example extracted from the *ICUC app*:** *Humeral shaft / ICUC Library / Simple /* ID: 12-SI-087. *The overview displays the main steps of the surgical approach and the highlights. Furthermore, the displacement, complexity, reduction and implant position is graded and an overall assessment indicates whether the procedure is recommended, to be discussed or rejected. X-rays and high quality pictures illustrating the step by step surgical procedure can be downloaded upon tapping on the overview x-rays.*

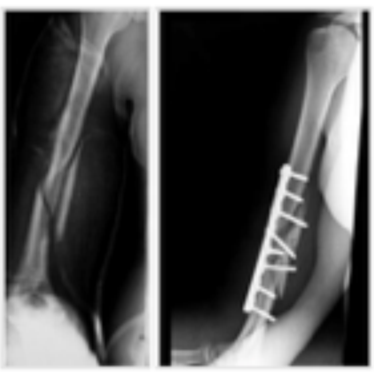

Fig. 7 and 8: *accident and first treatment.*
ICUC app case ID: 12-SI-087

Fig. 9: *64 weeks later breakdown in both main fragments. This was not a problem of imbalance but simply a problem of too small leverage in both main fragments.*
ICUC app case ID: 12-SI-087

Fig. 10: *Bridging with plate and adding an autologous bone graft. Strong imbalance of strength of fixation is clear.*
ICUC app case ID: 12-SI-087

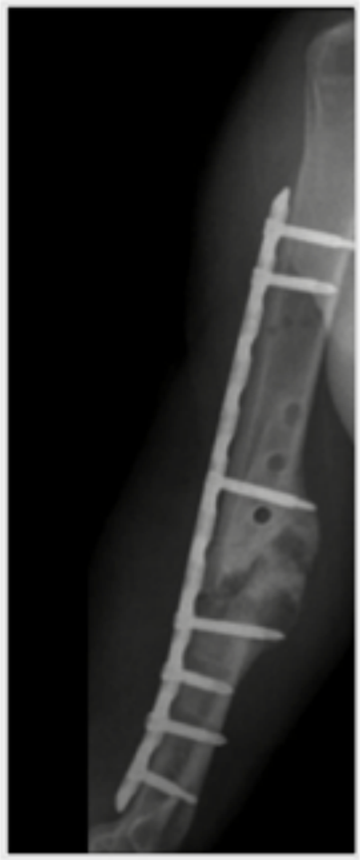

***Fig. 11:** Analyzing the postoperative x-ray the surgeon realized the danger of the imbalance and went in again adding a further distal fragment screw thus increasing the distal lever arm and with it saved the situation.* ICUC app case ID: 12-SI-087

***Fig. 12:** Final solid healing. The leverage of the distal coupling is smaller than the one of the proximal coupling. The critical issue is not the balance alone but good balance with sufficient leverage.* ICUC app case ID: 12-SI-087

***Fig. 13:** Full function after 6 weeks.* ICUC app case ID: 12-SI-087

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