Titanium vs steel in trauma surgery
Part I: Mechanical aspects[1]

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Introduction

The "street" opinions regarding the use of steel versus titanium as a surgical trauma implant material differ widely. Statements of opinion leaders range from "I do not see any difference in the biological behavior between steel and titanium in clinical application.[2]" to "I successfully use titanium implants in infected areas in a situation where steel would 'maintain' infection.[3]" Furthermore, some comments imply that clinical proof for the superiority of titanium in human application is lacking[4]. The following tries to clarify the issue addressing the different aspects more through a practical clinical approach than a purely scientific one. This includes simplifications.

Mechanical Implant Function

In fracture treatment the main function of the implant consists in solidly retaining the reduced position of the fracture fragments. Load tends to displace the fragments and, in turn, the stiffness of the implant resists displacement. The function of the implant, i.e. regaining painless function, depends primarily on the structural **stiffness** provided (Fig. 1). Titanium is ~50% as stiff as steel and so titanium is somewhat more tolerant at application. The **strength** of the implant, a secondary aspect, limits the amount of load resisted without permanent deformation or breakage (1). Stiffness and strength of the construct depend on the stiffness and strength of the material and of the more important dimensions (2). Therefore, the slight lack of strength of pure titanium can be offset by increasing some dimensions by only fractions of a millimeter. We keep in mind that the mechanical characteristics of the implant play only a role as part of a construct of different implants and bone.

Implant material for different applications of implants

Through cold working in steel and alloying in titanium different **combinations of strength versus ductility** can be produced. High strength / low ductility material is used for applications where no deformation is required such as Steinmann pins or Schanz screws of external fixators. The combination of high strength / limited ductility is used for screws and plates while the application in cerclage wires takes advantage of high ductility / limited strength (3). The grades of steel and titanium of the ISO material standards (5832) reflect these differences (Table 1).

ISO 5832	**1 WROUGHT STAINLESS STEEL**
ISO 5832	**2 UNALLOYED TITANIUM**
ISO 5832	**14 Ti $Mo_{15}Zr_5Al_3$**

Table 1: **ISO standards 5832 Implants for surgery metallic materials**

1 This is part I of two one-page papers of ICUC® App (www.icuc.net). The clinical aspects are dealt with in part II.
2 DH (pers.com.)
3 AF (pers.com.)
4 DH (pers. com.)

Lack of pre-warning of impending failure at screw insertion

In respect to the practical application of bone screws, for example, the **ductility**[5] of the implant is in addition to strength and stiffness a third important and critical factor. A ductile material provides **pre-warning** of impending failure when with increasing twist the torque does not increase anymore (Fig. 2) (4). The feeling is that the metal gives way. A ductile material like ISO 5832 steel grade 3 allows up to two full turns of twist without increasing torque before breakage. An experienced surgeon feels the change in the relation of twist and torque and limits torque.

If a surgeon with long experience in the application of steel screws switches from ductile steel to more brittle titanium, he risks failure due to twisting off of the screw head when torque increases while he waits for the non-existent ductile pre-warning of titanium. A surgeon who grew up using only titanium does not expect ductile pre-warning and limits the applied torque.

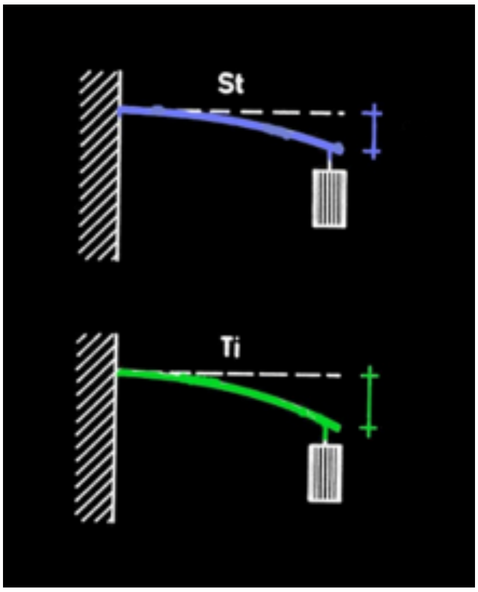

Fig. 1: Stiffness and deflection under load. The same load is applied to both bars. Titanium deflects more due to its smaller stiffness (3).

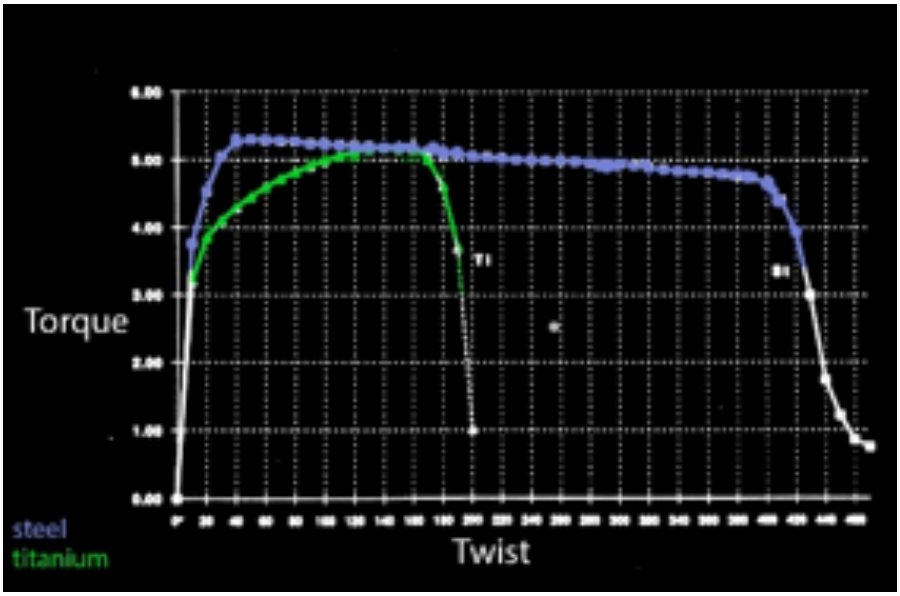

Fig. 2: Pre-warning. Twist / torque plot. Steel screw (blue): Increasing twist is enforced. Torque increases up to a peak value and thereafter the torque does not increase over a wide range of twist before failure occurs. When applying the same twist to a titanium screw after reaching peak torque, failure occurs without pre-warning. Peak torque is similar (3).

5 Ductility is the ability of a material to absorb energy and plastically deform without fracturing (Wikipedia). The term ductility is sometimes used here to encompass both types of plasticity, tensile (ductility) and compressive (malleability).

Ductility also plays an important role when, for instance, a plate is deformed to fit the bone surface. Today, with locked implants, neither of the two aspects of ductility plays a major role. A locked screw is tightened until the screw head is solidly locked within the plate hole; a process which consumes a major part of the applied torque while the screw thread experiences minimal torque with minimal risk of thread failure (Fig. 3). Locked plates, applied slightly elevated (to improve blood supply), do require minimal shaping. These facts require attention, understanding and familiarization.

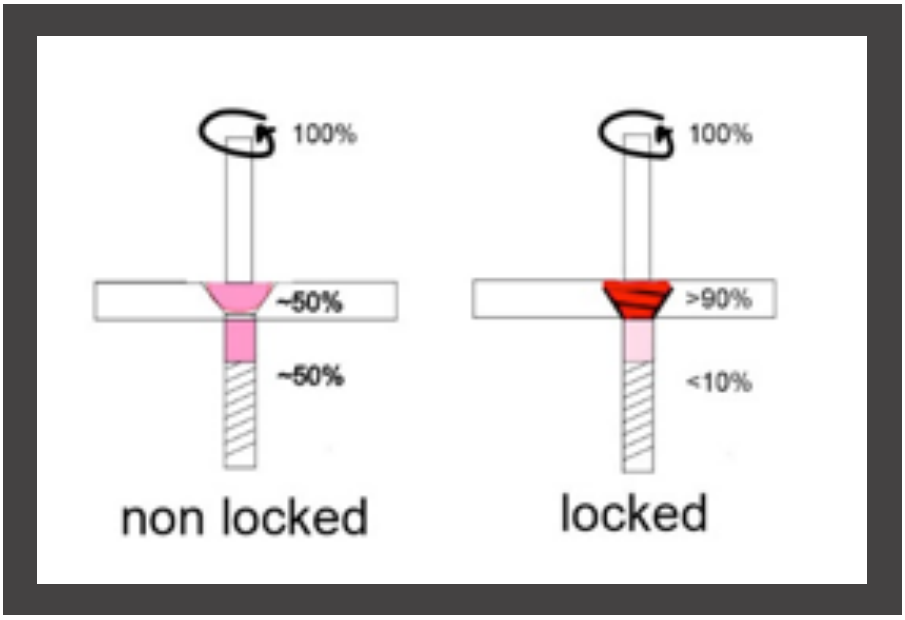

Fig. 3: Torque load of non-locked and locked screw threads. At insertion the main torque is used up at the screw to plate interface and the screw thread below is protected. At removal due to high interface friction of titanium to titanium at the screw to plate interface together with ingrowth of bone, the torque may obstruct disengagement.

Should one try to apply maximum torque for best stability of conventional plate screws?

In conventional application of plate screws, i.e. screws which press the plate onto bone, the surgeon often aims at applying maximum torque “for best stability”. Trying to apply maximum torque in an attempt to secure maximal stability does not make sense because approaching peak torque goes along with minimizing the amount of the additional (functional) load that the screw is able to resist.

Jamming of screws

Removing locked titanium screws may be very difficult. Considering locked screws, the characteristic of titanium, namely what is called “galling” or “micro welding”, i.e. that two identical titanium surfaces when compressed produce very large friction, was considered to be the one and only culprit for jamming. This problem might be resolved by coating one of the partners or by ion-implantation. Still, the explanation that the large torque required for removal is based on “galling or micro welding” did not consider that jamming was extremely difficult to produce on the bench. The observation of J. Álvarez and A. Fernández that bone grows into voids of the interface of the threads (5) and produces a large amount of friction offers an explanation that may allow to resolve the unacceptable problem. Preventing ingrowth or minimizing adherence of bone to the flanks of the thread needs to be studied (Fig. 4). Furthermore, the fact that between the end of the thread and the undersurface of the screw head a segment of the screw with smaller diameter must be overcome at removal requires an appreciable amount of torque. The latter torque together with bone ingrowth and with thread friction may result in a very demanding and unacceptable surgical procedure. Each of these elements needs attention.

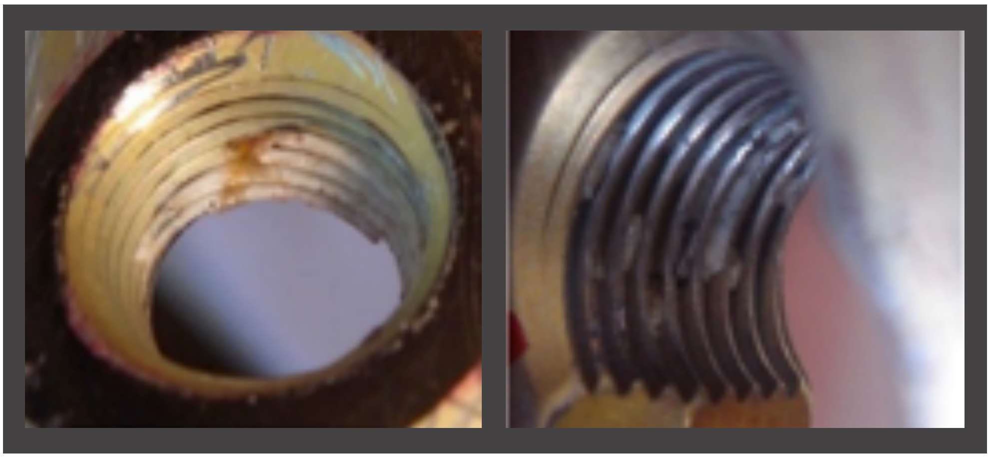

***Fig. 4:* Jamming of screws -** Plate hole (L) and screw head (R). Titanium friction may contribute to difficult removal but as this picture from Alvarez and Fernandez show bone ingrowth is the real culprit. Root and flanks of the thread interface are covered with sticky bone. On the crest of the thread only confined metal to metal contact (5).

The tolerance of implants to shaping

When an implant, such as a plate, is adapted to the bone surface, as usually done in non-locked conventional application, the question arises regarding the **effect of deformation on the remaining strength** of the implant. When small local deformation is applied either by single small bending or twist and/or by spreading the deformation over a large distance, like in the helical plate (Fig. 5) (6), the effect of the deformation may be understood as cold working, which may even increase strength. Repeated and/or large deformations producing large local strain will deteriorate strength (Fig. 6). This applies differently to both steel and titanium.

***Fig. 5:* Helical plate contouring over a tube.** *ICUC® App case ID: 32-CO-456 (6)*

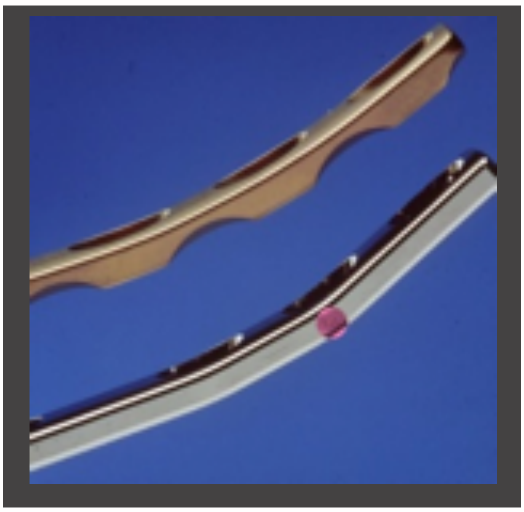

***Fig. 6:* Bending -** When shaping a plate to fit the bone surface sharp and repeated bends need to be avoided. Here smooth bending is supported by the continuous stiffness of the implant. The plate with discontinuous stiffness allows a sharper bend.

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