Pediatric supra-condylar humerus fractures – computer assisted finite element analysis of fixation configuration

LAMDAN R[1], SYMANOVSKY N[1], JOSKOWICZ L[2], LIEBERGALL M[1], GEFEN A[3], PELEG E[4]

[1]*Department of Orthopedic Surgery, Hadassah Hebrew University Medical Center, Jerusalem, Israel*
[2]*School of Engineering and Computer Science, The Hebrew University, Jerusalem, Israel*
[3]*Department of Biomedical Engineering, Tel-Aviv University, Tel Aviv, Israel*
[4]*Computer Assisted Surgery Laboratory (CASL), Hadassah University Medical Centre, Jerusalem Israel*

anatd@hadassah.org.il

Introduction: Supra-condylar humerus fractures (SCHF) are amongst the most common pediatric fractures requiring surgical stabilization (1). Closed reduction and percutaneous fixation with Kirschner wires (KW) is currently the standard of care (2). The number and configuration of KW used has been the subject of much research (3, 4). However, failure modes leading to loss of fracture reduction are not clear and have not been quantified.

It is hypothesized that the bonding condition at the bone-metal interface plays a major role on the stability of the fixated bone construct and that better understanding of the factors affecting this interface is essential for predicting fixation outcome.

The aim of this study is to compare the mechanical stability of the opt-used configurations for various loading modes and contact interactions at the KW/bone interface.

Methods: A Gartland type-III SCHF was introduced to a fourth generation composite saw bone (Sawbones®, Vashon, Washington, USA). The model was CT scanned with a slice spacing of 0.5mm and pixel size 0.3x0.3mm. The CT data was imported into AmiraDev (AmiraDev 5.2 Visage Imaging, Inc).

A model of the fractured humerus was constructed by manual segmentation; surface generation, andautomatic volumetric grid generation for each fragment. The fracture was then virtually reduced and KWs were placed at the desired configurations (Fig 1a-b). For each configuration, a separate model was generated. Material properties were assigned to the bone-model elements according to the manufacturer's data sheet; Young`s modulus E=16GPa and E=150MPa for the cortical and cancellous bone respectively. The KW were assigned a Young`s modulus of 200GPa.

Each of the models created in Amira was imported to a finite element application (Abaqus 6.9, DS-Simula) for structural analysis. For each of KW configuration four different torque forces load types were simulated (Fig 1c left): 1) a clockwise and counterclockwise torque with a magnitude of 1.5 NM (Newton/Meters); 2) a translational force with a magnitude of 30 N (Newtons) in the direction of the humerus shaft, and; 3) a shear force with a magnitude of 30 N in the direction parallel to the fracture plane. The results were normalized such that the maximum displacement for the crossed pin configuration with a coefficient of friction equal to zero (m = 0) was used as unity for each load configuration.

To assess KW-Bone interface pullout forces a uniaxial mechanical test was conducted (Instron 5544), utilizing a sheep humerus and 2mm KW’s. For each specimen, two pullout tests were conducted; 1) The KW was drilled through both cortices (Fig 1e) with a standard drill, 2) The KW was redrilled at high speed for three seconds without relocation. For each case, a load-displacement curve was constructed while retaining a constant crosshead speed of 1 mm/min.

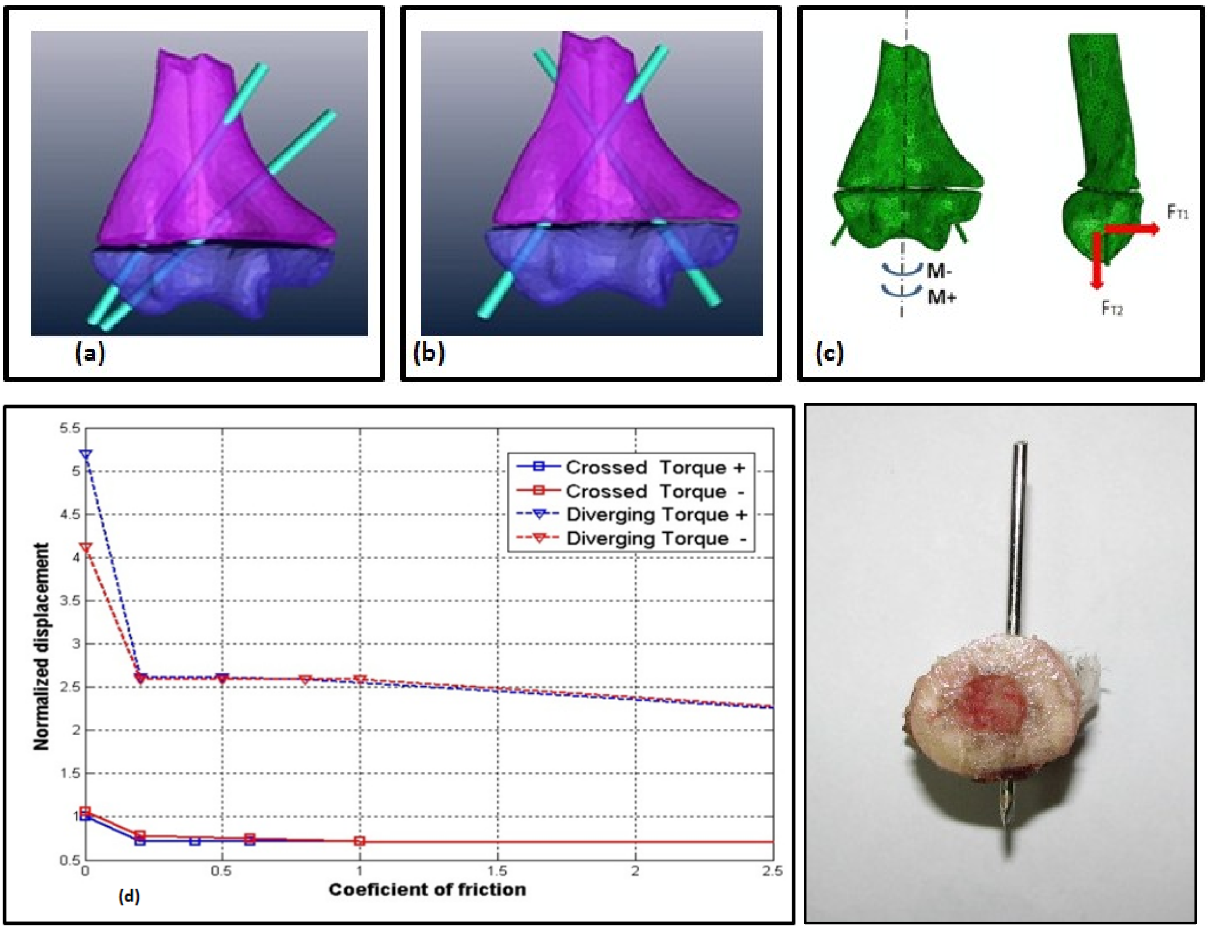

Figure 1: (a-b) Models of the fixated humerus prior to structural analysis diverging configuration, (c) torque (left) and translational (right) loading scenarios for the finite element simulation; (d) displacement as a result of torque for both configurations. (e) A KW drilled into a specimen of a sheep humerus.

Results: *Torque forces:* the crossed configuration was found to be almost independent of the bone-implant friction and was symmetric in terms of direction of the applied torque. The diverging configuration exhibited larger dependency on the bone-implant interface. This is especially noticed as the coefficient of friction (COF) reduced to values below m = 0.2.

Translational forces: the diverging configuration exhibited high sensitivity to reduction of the COF m = 0. Displacement of the fracture for m = 0 was substantially larger for the diverging configuration relative to the crossed configuration: 13.5 times and 19 times for the transverse and pullout directions, respectively. As the COF increased to values above m = 0.5, both fixation configurations performed in a similar manner.

Instron test: The average pullout force reduced from 26.5N to 16.6N as a result of re-drilling (a 25-75% reduction). This decline was seen in over 80% of trials regardless of the total bone and cortical diameters. The loads ranged from a max of 44.5Nto 0.9N.

Discussion: Stabilization of SCHF has been the subject of numerous studies. Relative stability of the different configurations and the risk for iatrogenic ulnar nerve injury has been in the center of the debate. Crossed KW configuration was shown in some clinical studies to be more stable than two lateral KW while others demonstrated no significant difference in stability. As ulnar nerve injury may occur in up to 15.4% of surgeries even if insertion of a medial KW is performed under direct vision, utilization of two lateral KW configurations offers the advantage of reducing this risk significantly.

The main finding of this study is that for a COF exceeding a threshold level (μ=0.2) the crossed KW configuration did not offer any mechanical advantage over the diverging lateral KW configuration.

However, for very low COF values ($\mu<0.2$) the crossed configuration exhibited improved performance when compared with divergent lateral KW (figure 1d).

The data demonstrates that the KW-bone bonding has a profound effect on the stability of the fixated bone construct. This is mostly evident when distraction forces are applied but also occurs, to a lesser degree, with rotational or translational forces. This may be a clinically relevant consideration in the fixation of pediatric SCHF since often, after unsuccessful attempts at stabilizing a fracture; KW's are passed through the same entry point a number of times. This, as shown in the mechanical test weakens the KW-bone interface and may lead to destabilization of the fixed bone and fracture displacement. To avoid weakening of the construct it is suggested that when re-drilling is necessary, a new entry point and pathway are chosen,

Conclusion: We have conducted a combined in-vitro mechanical test and finite element-based simulations of a fixated SCHF with different KW configurations, under various friction conditions. Under normal bone-implant interface bonding conditions, the two diverging lateral KW configuration offers adequate mechanical stability and may be the preferred choice of SCHF fixation.