PAEDRIATIC SUPRA-CONDYLAR FRACTURES OF THE HUMERUS – COMPUTER ASSISTED FINITE ELEMENT ANALYSIS OF FIXATION CONFIGURATION

R. Lamdan, N. Simanovsky, L. Joskowicz, M. Liebergall, A. Gefen and E. Peleg
Dept of Orthopaedic Surgery, Hadassah University Univ. Hospital, Jerusalem, Israel.

Abstract

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

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 0.3×0.3mm. The CT data set was imported into AmiraDev (AmiraDev 5.2 Visage Imaging, Inc). A uniaxial mechanical test was conducted in order to measure the KW pullout forces from the distal humerus.

A model of the fractured humerus was constructed with the following steps: 1) manual segmentation; 2) surface generation of each fragment, and; 3) automatic 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 $E = 16$ GPa and $E = 150$ MPa for the cortical and cancellous bone respectively. The KW were assigned a Young’s modulus of 200 GPa. 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 normalised such that the maximum displacement for the crossed pin configuration with a coefficient of friction equal to zero ($\mu = 0$) was used as unity for each load configuration. Similarly, for each of KW configuration four different translational forces load types were simulated (Fig 1c right): 1) a clockwise and counter clock-wise torque with a magnitude of 1.5 NM (Newton/Meters); 2) a
translational force with a magnitude of 30N in the direction of the humerus shaft, and; 3) a shear force with a magnitude of 30N in the direction parallel to the fracture plane. The results were normalised as described above.

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 $\mu = 0.2$. **Translational forces:** the diverging configuration exhibited high sensitivity to reduction of the COF $\mu = 0$. Displacement of the fracture for $\mu = 0$ 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 $\mu = 0.5$, both fixation configurations performed in a similar manner.

Stabilisation 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, utilisation 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 ($\mu = 0.2$) 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 fixed 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 important consideration in the rare SCHF in children with abnormal bones and possibly more commonly, when the KW-bone bonding was compromised after multiple attempts of passing the KW through the same entry point.

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.