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Biomechanical comparison of different external fixator configurations for stabilization of supracondylar humerus fractures in children

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ABSTRACT

Background: Currently, closed reduction and percutaneous pinning are considered the treatment of choice for displaced supracondylar humerus fractures. However, indications exist for the use of external fixation with Schanz screws. In this in vitro study, we evaluate the biomechanical properties of a new variation for external fixation and compare them to an established construct.

Methods: Twenty distal cadaver humeri (10 pairs) were allocated to 2 groups. The humeri of the first group were fixed by an external fixator consisting of Schanz screws and an oblique K-wire inserted from the distal radial cortex of the humerus, those of the second group were fixed by a new variation with the oblique K-wire inserted from the distal ulnar cortex of the humerus. Displacement and stiffness in static loading in internal and external rotation, as well as in extension and flexion were evaluated and compared.

Findings: The variation of the external fixator of the second group proved to be statistically significantly superior to the variation of the first group in internal rotation loading ($p > 0.05$). In sagittal loading conditions and external rotation loading, the variations were equally stable ($p > 0.05$). There was no significant effect of the samples' bone density on displacement and stiffness values in any direction of loading.

Interpretation: In cases of pediatric supracondylar humerus fractures when an external fixator is used for osteosynthesis, the insertion of an additional ulnarly inserted anti-rotation K-wire should be preferred to a radially inserted one as it reduces secondary displacement of the distal fragment.

1. Introduction

Elbow fractures belong to the most common fractures of young children with supracondylar humerus fractures accounting for 50–58% of them (Houshian et al., 2001; Lvv et al., 2013; Marzi, 2010; Skaggs & Pershad, 1997; Weinberg et al., 2002). In most cases, unstable fractures are fixed by closed reduction and percutaneous pinning as the treatment of choice (Mallo et al., 2010; Omid et al., 2008; Pirone et al., 1988; von Laer et al., 2002; Wilkins, 1997). However, following Slongo, many indications exist to prefer external fixation with Schanz screws (FES) (Slongo, 2014; Slongo et al., 2008). When closed reduction cannot be achieved by common methods, FES has an advantage over percutaneous pinning and an external fixator consisting of K-wires (Lv, 1997) (external fixator by von Laer) as it facilitates reposition of the fragments with the help of the larger diameter Schanz screws (Slongo et al., 2008). Further indications are fractures that show a displacement in the sagittal plane of more than 30° which are by definition oblique fractures, comminuted fractures that cannot be sufficiently fixed by K-wires, fractures which were initially fixed by percutaneous pinning and displaced again, or open fractures with the risk of a developing compartment syndrome (Slongo, 2014; Slongo et al., 2008). An established FES-construct is the stabilization with radially placed Schanz screws and an additional oblique K-wire, inserted into the radial epicondyle, and connected to the fixator rod (rFES) (Fig. 1) (Slongo, 2014; Slongo et al., 2008). A new variation of this external fixator was developed hypothesizing that an additional ulnarly inserted anti-rotation wire (uFES, Fig. 1) – instead of the radially inserted one – would provide further stability to internal rotation as it does in the method of crossed pinning and would additionally stabilize the ulnar column of the distal humerus (Lee et al., 2002; Srikumaran et al., 2012; Vlahovic & Bumci, 2002; Weinberg et al., 2007; Zionts et al., 1994). In pilot experiments using synthetic humeri, we compared the uFES to crossed pins (as this is the treatment of choice for supracondylar fractures in children) and to the established rFES.(Hohloch et al., 2015) The uFES showed the best results in any of the directions of loading we tested (internal rotation, external rotation, extension, and flexion). The object of this cadaver study was to compare this new configuration (uFES) to the established one (rFES) on human specimens, thus in conditions that are closer to the in vivo situation compared to sawbones.

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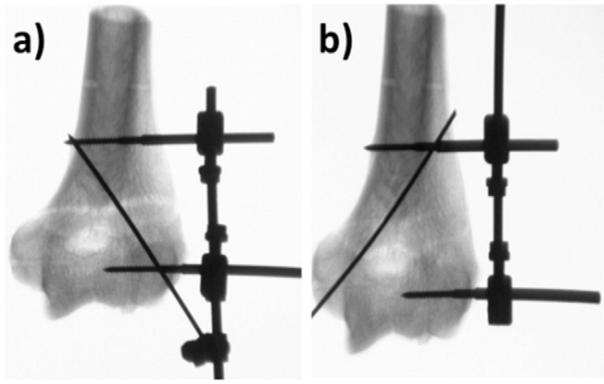

Fig. 1. Radiological pictures of the two methods of external fixation. a) rFES = external fixator with radially inserted K-wire, connected to the rod. b) uFES = new variation of the external fixator with ulnarly inserted K-wire.

2. Methods

For biomechanical testing, 10 fresh-frozen pairs of distal cadaver humeri were used. The soft tissues were removed to the bone and the specimens were allocated to two groups of 10 humeri each and were tested in pairs. The humeri underwent a DXA bone densitometry and the bone densities of the specimen in both groups were statistically compared. The specimens were thawed 24 hours before the experiment started.

A 30° oblique osteotomy was created with a standardized jig starting at the proximal edge of the olecranon fossa descending to the coronoid fossa (Fig. 2). Therefore, an oscillating fine-blade saw was used with a saw-blade of 10 mm width. Anatomical reduction of the fragments followed and osteosynthesis was in all cases performed by the same surgeon.

2.1. Group 1 (rFES)

After reduction of the fragments, the first 3.0 mm Schanz screw (Synthes® GmbH, Solothurn, Schweiz) was inserted into the proximal fragment, 4.5 cm proximally to the center of radial epicondyle. Care was taken that it was placed perpendicularly to the humerus shaft. The second 3.0 mm Schanz screw was inserted vertically to the long axis of the distal fragment into the radial epicondyle. In both cases, the ulnar cortex was engaged. Finally, the screws were attached to a 4.0-mm stainless steel rod. Screws and rod were connected by tube-to-tube clamps. Finally, an anti-rotation 2.0-mm K-wire was inserted from the radial cortex of the distal fragment, crossed the distal Schanz screw and engaged the ulnar cortex of the proximal fragment, 6 cm proximally to the distal end of the distal humerus. The K-wire was fixed to the rod (Fig. 1).

2.2. Group 2 (uFES)

The insertion of the two 3.0 mm Schanz screws followed the description of the external fixator described in group 1 and they were fixed to the rod accordingly. However, in this case, the anti-rotation 2.0 mm K-wire was inserted from the ulnar cortex of the distal fragment. Due to its position, it could not be fixed distally as its end lay opposite to screws and rod. (Fig. 1)

To control correct positioning of the implants, a radiological examination was performed.

Afterwards, the humeri were shortened to a length of 15 cm and fixed in a custom-built apparatus (Fig. 3) to ensure that the rotational floating center passed straight through the diaphysis.

2.3. Biomechanical tests

A material testing machine UTS 20/testControl ® (Zwick/UTS Testsysteme, Ulm, Deutschland) was used, the TestXpert® II software (Zwick, Ulm, Deutschland) recorded displacement of the loading cell at a frequency of 500 Hz and calculated stiffness values (Nm/° for internal and external rotation loading, respectively, N/mm for extension and flexion loading). Every single bone-implant-construct of each group was tested in 20 sinusoidal cycles of force-regulated internal rotation, external rotation, extension and flexion loading at a frequency of 0.5 Hz. For rotational loading, the bones were fixed in a custom-built apparatus (Fig. 3). For extension and flexion loading, the humeri were freed from the apparatus and were distally fixed in a bar clamp. Extension loading was performed 8 cm, flexion loading 9 cm proximally to the distal end of the humerus. For internal and external rotation loading, a maximum torque of 1.5 Nm was applied and extension and flexion a force of 10 N was carried out.

In addition, recording of angular displacement was performed with the aid of an ultrasound-based motion analysis system CMS 20 (Zebris Medical, Isny, Germany) which had already been approved in several biomechanical studies (Konstantinidis et al., 2010, 2011a,2011b, 2012, 2013). Measurement is fulfilled by transmission of ultrasound waves. Motion in all three degrees of freedom is registered at an accuracy of 0.1 mm. Hereby the values of the plane in which the largest displacements occurred during loading conditions could be analyzed.

2.4. Statistical analysis

Statistical analysis was performed in collaboration with the Department of Medical Biometry and Medical Informatics of the University of Freiburg and by the use of SPSS Version 21 (IBM SPSS Statistics). An a

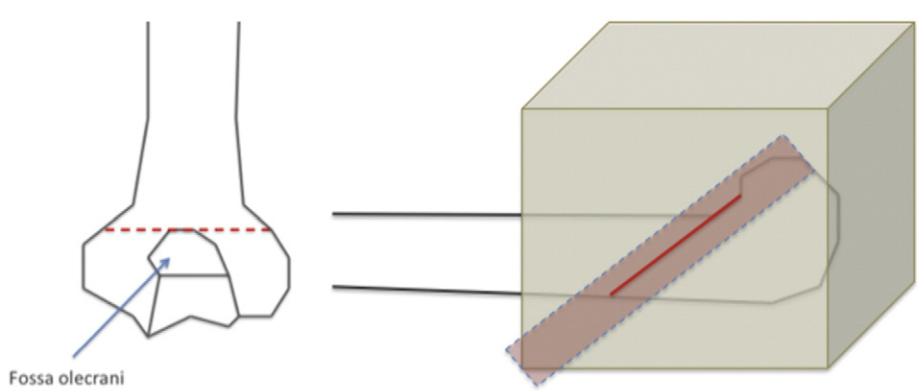

Fig. 2. Schematic picture of the osteotomie. Left: Posterior side of the humerus with the olecranon fossa; the dashed line shows the starting line of each osteotomy. Right: Positioning of the distal end of the humerus in the jig that allowed sawing alongside a 30° angle.