Development of a Novel Pediatric Forearm Fracture Treatment: Simulation, Prototype and Evaluation

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Background

Distal forearm fractures (DFF) are among the most common childhood injuries with current treatments split between conservative casting with closed reduction, and surgical techniques, for larger displacements [1, 2]. A treatment gap exists for moderately displaced DFF, which are associated with a higher rate of improper reduction when treated conservatively [2]. The fracture therapy presented in this study aims to fill this gap by introducing a novel reduction method without the need for invasive surgery [3].

Novel Fracture Treatment

A hinged cast system, with adjustable external angulation, counteracts the initial fracture angle to maintain a successful fracture reduction. The mechanical behavior is achieved via a cast attachment, positioned between the padding and casting material of the forearm cast (Fig. 1). Three hooks transfer an external tension to the cast, causing a hinge-like rotation (Fig. 2).

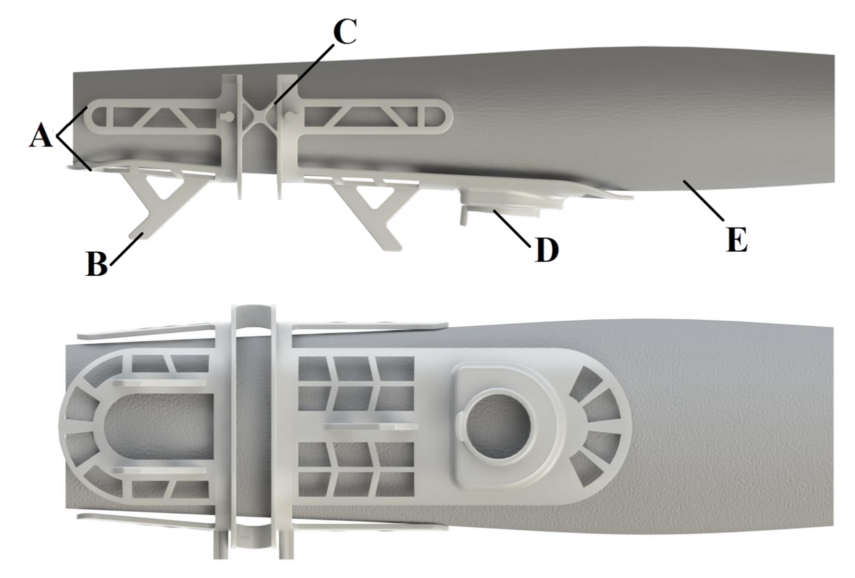

Fig. 1- Cast attachment placed over padding : (A) main body, (B) guide hooks, (C) truss joint, (D) dial mount (E) cast padding.

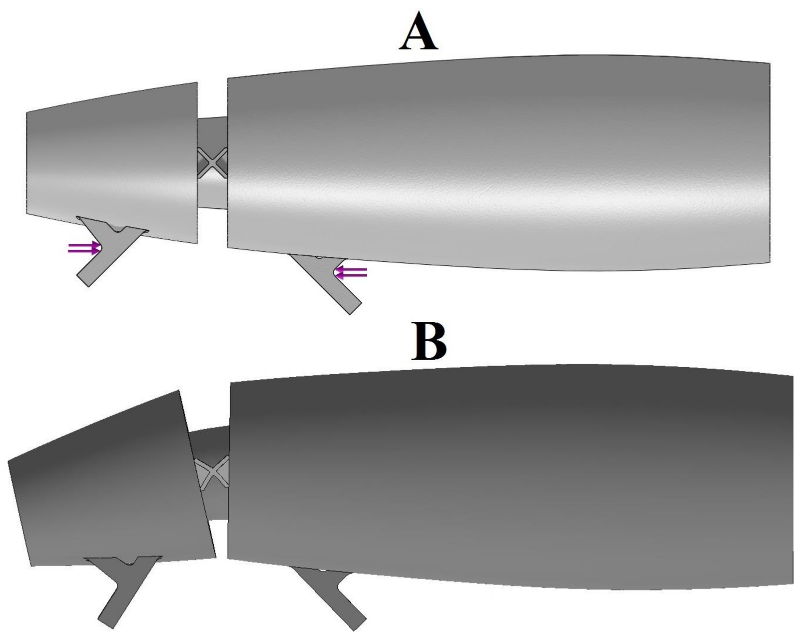

Fig. 2- Mechanical behavior of system: (A) before and (B) after the external load is applied (purple vectors).

Prototype

- CAD simulation revealed design changes needed for improved integration of cast attachment and prevention of material failure
- Redefined geometry reflects pediatric forearm anatomy and reduces stress concentration in truss joint
- Biomechanical pediatric forearm phantom developed for prototype (Fig. 5): cast silicone-based phantom with embedded 3D-printed bone models simulates both-bone complete DFF with 15° fracture angle [4]
- Boa closure system (www.theboasystem.com) applies external load

Fig. 5- Assembled prototype of cast system. The forearm phantom is covered with a cotton cast sleeve and the redesigned cast attachment (3D-printed from polyamide 12) is placed over the sleeve. Synthetic casting material secures the cast attachment to the forearm.

Biomechanical Simulation

- Age-specific CAD model of pediatric forearm and cast system (Fig. 3)
- Each component defined by modulus of elasticity, Poisson's ratio, and density [4]
- Discretized with solid, tetrahedral mesh (element size 1.0-5.0 mm)
- Linear static FEA for applied loads of 25 - 100 N
- Angular displacements calculated to derive external versus internal angulation of the system (Fig. 4) and max. von Mises stress examined for potential material failure [5]

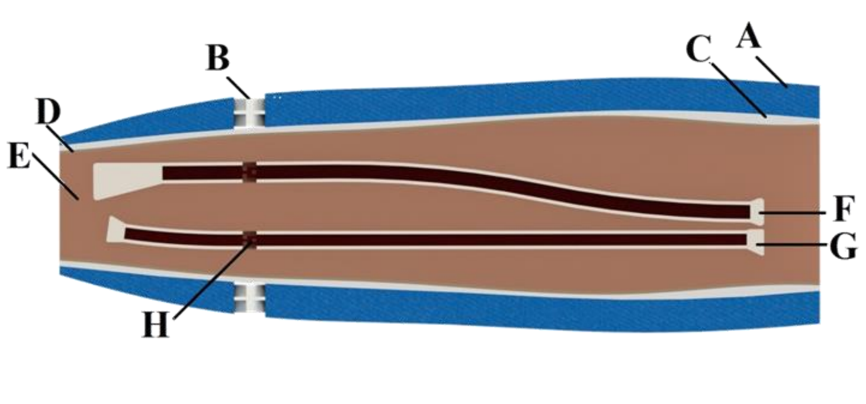

Fig. 3- Cross-section of CAD forearm model and cast system: (A) casting material, (B) imbedded cast attachment, (C) padding, (D) skin, (E) soft tissue, (F) radius, (G) ulna, (H) fracture site (hinge-joint).

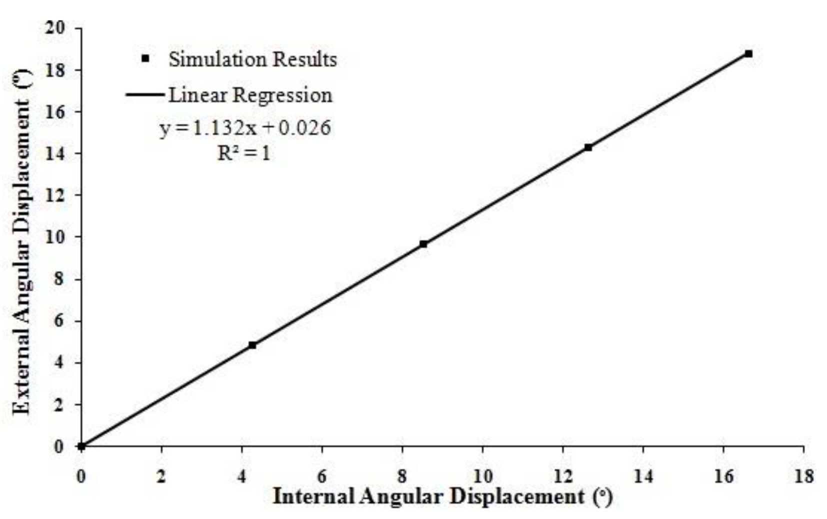

Fig. 4- External versus internal angular displacement. Markers show simulation values and derived linear regression with an R^2 value of 1.

Evaluation and Results

- Testing and radiographic imaging of prototype performed in the Department of Pediatric Surgery, UKSH, Lübeck Campus
- Lateral radiographs of system before and after reduction (Fig. 6)

Table 1: Summary of lateral radiographs describes the measured angle, calculated fracture angle, and external cast angle before and after manipulation.

	Measured Internal	Calculated Internal	Cast Angle
Initial	165.06°	14.94°	0°
Manipulated	179.81°	0.19°	16.57°

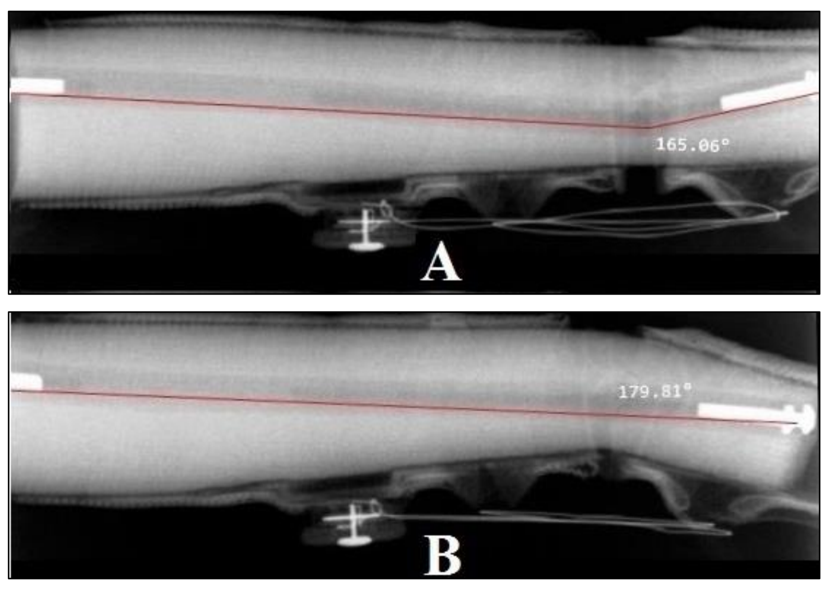

Fig. 6- Lateral view of cast system (A) before and (B) after manipulation.

Conclusion and Future Work

Results of the study support the capability of the novel treatment to reduce a 15° initial fracture to < 1° of residual angulation. Future models should consider various muscle states to evaluate total treatment scope.

References

[1] Rodriguez-Merchan EC. Pediatric fractures of the forearm. Clin Orthop Relat Res. 2005. 432. 65–72.
[2] Jordan RW, Westacott D, Srinivas K, and Shyamalan G. Predicting redisplacement after manipulation of paediatric distal radius fractures: the importance of cast moulding, Eur J Orthop Surg Traumatol. 201525:5, 841–845
[3] Klein S, Hainer F, Luenz S, and Wünsch L. Repositionshilfe. Patent DE 10 2015 121 123
[4] El-Shaffey, H. Simulation of a biomechanical model and construction of a pediatric forearm phantom in the development of a novel fracture treatment. Lübeck University of Applied Sciences. Master Thesis. 2017
[5] Cantrell J, Rohde S, Damiani D, Gurnani R, DiSandro L, Anton J, Young A, Jerez A, Steinbach D, Kroese C, and Ifju P. Experimental Characterization of the Mechanical Properties of 3D Printed ABS and Polycarbonate Parts. Cham: Springer International Publishing. 2017. 89-105.

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