Abstract

Distal forearm (DF) fractures are among the most common childhood injuries, with current treatments split primarily between conservative treatment with closed reduction and surgical techniques. This leaves a gap in the treatment of moderately displaced fractures, which carry a high risk of improper reduction when treated conservatively, but are not large enough to warrant invasive surgery. Manipulation methods such as cast-molding or wedging have been proposed for improved fracture reduction. However, their success is limited by casting material stiffness, radiograph measurements, and tissue swelling. Currently, no standard method for correction of or changes to the initial reduction of pediatric DF fractures is available.

To address this need and the current treatment gap, a novel pediatric fracture reduction method has been proposed. This treatment involves a hinged cast system with an adjustable external angulation, to correct initial fracture angle and maintain a successful reduction throughout the healing process. This closed, indirect reduction method allows for simple corrections or further cast manipulations. The purpose of this study is further development of this concept, through evaluation of the mechanical behavior of the system with a biomechanical forearm model. The specific aims are to examine the forces needed to manipulate the fracture angle, to derive the relationship between the external and internal angulation, and to implement necessary design changes based on study findings.

An initial CAD model of a distally-fractured pediatric forearm with the novel cast system, was developed using age-specific, anthropometric, empirical data, to reflect the anatomy and specific material properties of the system. The behavior, displacements, and stresses were analyzed through a linear, static, finite element simulation. The simulation results were used to redesign the cast system, resulting in two new concepts: one with lower stresses and lower flexibility (LSLF) and one with higher stresses and higher flexibility (HSHF). The design changes focused on material failure prevention, improvement of integration with casting material, and optimization for current casting procedure. Finally, a biomechanical, pediatric, forearm phantom was designed for the functional mechanical testing of the redesigned concepts. This silicone-based phantom, with age-specific material properties (modulus, Poisson's ratio, and density) and embedded 3D-printed bone models, was constructed to simulate a both-bone, complete, DF fracture, with a 15° initial angulation. Radiography was used to measure angular displacements during testing.

The cumulative results support the novel cast system as a potential treatment for pediatric DF fractures. The CAD model and tissue phantom indicate the ability of both redesigned concepts to manipulate a 15° fracture, with 0-1° of residual angulation. The simulation-derived relationship between internal and external angulation was shown to be piecewise-linear, with an increase in the external displacement resulting in an increase in the difference between the displacements. This prediction was partially validated by the mechanical testing. The potential for material failure due to stress concentration was reduced in the LSLF concept, with only partial material failure observed in in the HSHF concept. However, the LSLF concept required notably larger forces to manipulate the fracture than the HSHF concept.

Future work should expand the existing biomechanical model to include variable muscle states, to evaluate total treatment scope. Additionally, the relationship between stress reduction and mechanical function should be further optimized in future cast system concepts.