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Biomechanical Modeling of Pediatric Clubfoot

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PROJECT TITLE: Biomechanical Modeling of Pediatric Clubfoot
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INTRODUCTION

Idiopathic clubfoot is a congenital deformity of the lower extremity affecting nearly 200,000 newborns each year worldwide [1]. This deformity presents with bone displacement and malformation, as well as alterations in the soft tissue [2]. Morphological studies have noted a fibrotic mass of tissue encapsulating the medial and posterior aspects of the foot [2-4]. The Ponseti Method is a conservative treatment that progressively repositions the clubfoot with weekly castings [4]. Although this treatment is widely accepted and successful, relapse of the deformity does occur. Untreated and under corrected clubfoot can result in abnormal gait, pain, and further deformity.

Relapse is dependent upon both treatment compliance as well as the nature of the clubfoot deformity [5]. It is hypothesized that the contractures of medial fibrotic mass tissue (MFMT) surrounding the foot may hinder correction. Previous studies have focused on histomorphological and immunohistochemical testing to investigate clubfoot soft tissue morphology and pathogenesis [3,4]. Few studies have investigated the mechanics of the MFMT or its effects on the success of treatment. Likewise, a quantification of the collagen fiber organization of this tissue and how it may relate to the tissue mechanics has yet to be assessed. The goals of this study are: 1) to model the structure and behavior of the medial fibrotic mass tissue in order to gain structural and functional insight, and 2) to employ this information to improve corrective approaches to long term clubfoot correction.

SIGNIFICANCE

Little is known about the material properties or mechanical behavior of the MFMT, thus longer term strategies for treatment of severe clubfoot are not based upon quantitative principles. Mechanical tests can provide information on the material properties and time-dependent (viscoelastic) behavior of the soft tissues as they respond to corrective treatment. To better understand the deformation of the MFMT during conservative (progressive casting) correction of clubfoot, its microstructure and mechanical behavior must be characterized. Information gained from this study will increase our understanding of clubfoot tissue response to load, which may lead to improved strategies for long term clubfoot correction.

FORWARD THINKING/INNOVATION

The proposed study is an investigation of tissue mechanics of clubfoot medial fibrotic mass tissue (MFMT). A low cost, uniaxial mechanical testing device for miniature soft tissue specimens has been designed and is being validated for application. This machine, comprised of a linear actuator, force transducer, custom grips, and video camera, is controlled by a custom-written protocol in LabVIEW. The MFMT, excised from patients undergoing routine clubfoot surgery (IRB approved), will undergo stress relaxation tests at different strains in order to quantify the elasticity of the tissue, as well as to model its material behavior over time. In addition, this tissue will undergo histological imaging in order to quantify the collagen fiber orientation and degree of organization. The relationship between the tissue mechanics and microstructure may provide yet another avenue for more effective correction through applied imaging technologies.

STUDENT INVOLVEMENT

Tamara Cohen will lead all aspects of this study as a major component of her dissertation. This includes design, validation, and testing of the soft tissue testing machine to be used for stress relaxation testing of the MFMT, mathematical modeling the tissue behavior based on test results, and characterization of clubfoot collagen fiber orientation using Image Pro Plus software. Tamara will contribute as the primary author under the direction of her mentor and dissertation committee in the publication of results in the peer reviewed, scientific and clinical literature.

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