FINITE ELEMENT MODELLING OF FLEXIBLE FLATFOOT

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INTRODUCTION

The foot is a complex structure which bears high loads during static stance and gait. It allows for efficient transfer of energy when moving, and support when motionless. Children are not are born with a longitudinal arch in the foot; rather, it develops as they grow [1]. Not all children will outgrow their flat feet, and these cases can progress to be painful and sometimes disabling [2]. Flexible flatfoot is often associated with a tight Achilles tendon, but it is unclear exactly how this influences arch geometry. This paper aims to compare factors contributing to flexible flatfoot through finite element modelling of the foot.

METHODS

T1-weighted MRIs (3.0T Philips Activa, Royal Philips Electronics, Netherlands) of the right foot of a 23-year-old female with normal feet were obtained. Geometries of oblique slices through the five rays of the foot were extracted using ANALYZE 8.1 (AnalyzeDirect, Inc., KA, USA). Manual segmentation of bony structures, cartilage/joint space, fat pad and other soft tissues was performed. Any discontinuities in segmentation contours were corrected using SolidWorks (SolidWorks, MA, USA). Final geometries were imported into the finite element package ANSYS11.0 (ANSYS Inc., PA, USA). All five models (one for each ray) were meshed with 2D solid elements (Figure 1, top).

Material properties for bone were defined using a weighted average of trabecular and cortical bone properties [3]. The plantar fascia and ligamentous structures were modelled using tension-only truss elements [3,4,5]. Insertion sites of the fascia and other ligamentous structures were defined to conform to standard anatomical descriptions. Cross-sectional areas for the plantar fascia and ligaments were based on those used by [3] and [4], respectively. The joints were fused using cartilage [3,5] and a soft fat pad was defined. Additional soft tissue with material properties given by [4] was defined in the space below the bone structure. A steel floor plate was added to each model and constrained to move in the vertical direction only. All materials were idealized as linearly elastic and isotropic.

The foot was assumed to bear half body weight applied through the floor plate, with a distribution of load across the five rays of approximately 25%-19%-19%-19%-18% from the first to fifth rays respectively [3]. On each ray model, a uniform vertical load of 29 N was applied to the posterior aspect of the calcaneus to simulate the Achilles tendon force [3,5] (Figure 1, bottom). The values of the Achilles tendon force, plantar fascia stiffness, plantar fascia cross-sectional area (CSA), ligament stiffness and ligament CSA were varied individually from zero to twice their baseline values. An increase in the applied Achilles tendon force was used to model the tight Achilles tendon often seen in subjects with flat feet [6]. The outcome parameters of interest were total change in arch height, metatarsal deflection, calcaneal deflection, and plantar fascia stress.

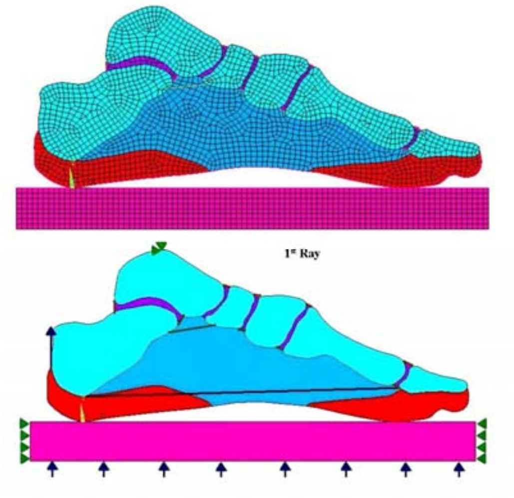

Figure 1: Finite element model, example of 1st ray. Only the proximal phalanges are included. Converged mesh (top) and geometry, loads, and boundary conditions (bottom).

RESULTS AND DISCUSSION

In the first, second and third rays, the plantar fascia had the greatest influence on the overall loss in arch height. Even in the lateral rays, the effects of the plantar fascia laxity on the total change in arch height were substantial. In the medial rays (first, second and third), the integrity of the plantar fascia had the only substantial effect on metatarsal deflection. However, in the lateral two rays, the other ligaments appeared to be important in minimizing metatarsal deflection and overall losses in arch height.

The effect of the Achilles tendon force increased from the medial rays to the lateral rays, with the total decrease in arch height of the fourth and fifth rays being almost as dependant on Achilles tendon force as on the integrity of the plantar fascia. In addition, the Achilles tendon force had a minimal effect on the metatarsal deflection of the five rays with the greatest influence seen in the calcaneal deflection.

This study shows the importance of modeling all five rays of the foot in order to understand the factors affecting flatfoot. Limitations include the basic joint models, the lack of foot muscles, and the absence of links between rays.

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