CADAVERIC SIMULATION OF A PES CAVUS FOOT

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INTRODUCTION:

Pes cavus is an umbrella term that encompasses several high arch conditions; it can affect primarily the hindfoot or primarily the forefoot, or it can affect the foot more globally.1,2,3 Though a universally accepted definition of pes cavus is unavailable, there are common trends mentioned in discussions of the pes cavus deformity in the literature.1,2,3,6

These include inversion of the calcaneus, inversion of the midfoot, adduction of the forefoot, plantar flexion of the first metatarsal and an increase in force on the lateral border of the foot.

Several muscular imbalances stemming from neurologic disorders have been cited as underlying factors for pes cavus development.1,2,5,6 Mann describes a strong peroneus longus (PL) and tibialis anterior (TA) in Charcot-Marie-Tooth disease.7 Dehne notes spasticity of the TA, TP, flexor hallucis longus (FHL) and flexor digitorum longus (FDL) after stroke resulting in equinovarus.5

The goal of this study was to produce a cadaveric model of a pes cavus deformity in an otherwise normal foot. The model was created by attenuating ligaments and generating muscle imbalances. We are unaware of any previous pes cavus cadaveric model. Such a model, if repeatable, would be useful in evaluating corrective surgical procedures.

METHODS:

In this IRB-approved study, we tested six freshly frozen, unreserved human cadaver feet (mean age of 75.2 ± 8.4, 3 male, 3 female, range 65-88 yrs) on a customized loading frame capable of loading the extrinsic muscles and tibia/fibula via eight pneumatic cylinders.6 The feet were screened for osseous deformity by X-ray and gross examination. Each foot was dissected above the level of the medial malleolus to expose the tendons of the TA, PL, TP, FHL and FDL muscles as well as the Achilles tendon. A hole was drilled in the tibia and fibula to insert compressive rods. Tendons were attached to the loading frame with plastic clamps and nylon cords.

We drilled holes in the tibia, talus, calcaneus, navicular, medial cuneiform and 1st metatarsal to insert carbon fiber rods (diameter 4.78 mm) which were secured with super glue. Polhemus Fastrak™ electromagnetic sensors were then attached to the rods using acrylic mounts, allowing us to track spatial orientation and movements of the bones of interest using the Fastrak system. Peak pressure and force distribution were measured using a Pedar insole and Novel analysis software.

The dorsal tarsometatarsal ligament (between the medial cuneiform and 1st metatarsal) and the dorsal intercuneiform ligament (between the medial and intermediate cuneiforms) were weakened by making five incisions with a 15-blade scalpel parallel with the ligament’s fiber orientation.7 The foot was mounted in the loading frame at 7° dorsiflexion using a wooden ramp. Tendon forces were calculated using muscle cross-sectional areas, maximum specific tensions, cosines of pennation angles and EMG activities to simulate physiologic midstance (30% of the gait cycle)4,10. Following ligament weakening, the TA and TP were overpulled at 1 Hz for one hour (3600 cycles), with the other extrinsic muscles pulled at 1/4 physiologic. This served to further attenuate the ligaments and increase the pes cavus deformity.

To maximize overpulls, axial compression and muscle forces were set at 1/8 of body weight during data collection. Data for midstance and the following three non-physiologic conditions were collected:

1. Overpull of Achilles, TA, TP, FHL, FDL
2. Overpull of Achilles, PL, TP
3. Overpull of PL, TP; underpull of TA, PB

The testing order of these conditions was randomized during data collection. Overall differences from midstance and differences among the three imbalances were assessed using linear mixed effects models.

RESULTS:

Overall, there were several significant changes between the balanced and unbalanced conditions (p<0.05), including plantar flexion of the 1st metatarsal, and inversion of the calcaneus, navicular and medial cuneiform, as well as increased loading in the medial and lateral forefoot. When considering the three muscle imbalances, the largest changes were found with the first imbalanced condition, as the following angles were all significantly different from the second and third conditions (p<0.01). The calcaneus inverted [mean (standard deviation)] relative to the talus by 3.3° (1.7°), while the navicular and medial cuneiform inverted relative to the talus by 9.8° (5.2°) and 11.0° (4.74°), respectively. Also, the 1st metatarsal adducted relative to the talus by 6.1° (6.1°), and there was an increase in force in the lateral forefoot of 8.7 N (2.2 N). Though not statistically significant, the 1st metatarsal did trend towards planar flexion relative to the talus by 3.0° (2.2°) and force increased in the lateral midfoot 9.7 N (8.6 N). The calcaneus was also significantly internally rotated by 3.5° (3.3°), a finding not typical of the cavus foot deformity.

The other imbalanced conditions did not produce as many significant differences from either midstance or when compared to other conditions. In both the second and third condition, the medial forefoot peak pressure and force did show a significant increase from midstance and the first condition, consistent with strong contraction of the PL.

DISCUSSION:

Different combinations of overpulls of the Achilles, TA, TP, FHL and FDL produced a repeatable model consistent with clinical measures of the pes cavus deformity. The calcaneus showed significant inversion and, consistent with an elevated medial longitudinal arch, the midfoot (i.e., the navicular and medial cuneiform) showed significant inversion. The increase in lateral force distribution reflects the weight-bearing changes of the pes cavus deformity. The increase of the forefoot further supports the validity of this cadaveric model as a tool to study pes cavus feet. Potential limitations of the study include our inability to simulate long-term osseous changes, constriction of the plantar aponeurosis and dysfunction of the intrinsic foot musculature.1,8

Further studies could focus on corrective procedures for pes cavus feet. For example, an ostetomy or tendon transfer could be performed on a cadaver foot after the pes cavus simulation. The foot could then be returned with the same protocol of this experiment. Corrective efficacy could be quantified by loading as the same parameters as the overpull that produced the pes cavus deformity in our study. An effective procedure should reduce the observed pes cavus characteristics.

ACKNOWLEDGEMENT:

This work was supported in part by the Medical Student Research and Training Program at the Univ. of Washington, and the Dept. of Veterans Affairs, Rehabilitation R&D Service grant number A2661C.

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Poster No: 1206

53rd Annual Meeting of the Orthopaedic Research Society