CADAVERIC MODEL OF A DORSAL BUNION

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Introduction:
The dorsal bunion is primarily a sagittal plane deformity of the first ray. It is characterized by dorsiflexion of the medial cuneiform and first metatarsal and plantar flexion of the halluc. This deformity is also characterized by increased stiffness and possibly subluxation of the first metatarsal phalangeal joint (MTPJ). An underlying cause of the dorsal bunion is thought to be muscle imbalances along the first ray. In particular, the overpull of the flexor hallucis longus and/or the tibialis anterior and underpull of the peroneus longus.

The purpose of this work was to develop a cadaveric model of the dorsal bunion deformity from a healthy foot by attenuating ligaments and generating muscle imbalances. To date, we are unaware of any such cadaveric models, which in the future, could be used to determine the efficacy of surgical procedures for correction of the dorsal bunion.

Methods:
Five fresh-frozen cadaveric feet were tested in this institutional review board approved study (age range, 65-90 yrs, mean age, 76.6 ± 9.6, 3 female, 2 male). The feet were first assessed, via X-ray, for previous surgical intervention or osseous deformities that might obscure normal foot mechanics. The feet were then dissected to expose the extrinsic muscle tendons of the foot above the metatarsoarticular line. Plastic tendon clamps were applied to the following tendons: peroneous longus (PL), tibialis anterior (TA), flexor hallucis longus (FHL), flexor digitorum longus, tibialis posterior, peroneus brevis and Achilles.

Pilot studies indicated first ray ligament attenuation was necessary to generate the deformity. The plantar medial cuneiform-first metatarsal ligament was visualized and attenuation was performed by placing five longitudinal punch incisions using a 15-blade scalpel. In addition, Lis Francs ligament was approximated and completely sectioned. Placement of bone pins into the talus, medial cuneiform, first metatarsal and proximal phalange of the great toe allowed quantitative measurements of angular bone position to be gathered. Pilot holes were drilled (4.37 mm bit) and carbon fiber rods (4.78 mm) were tapped into the aforementioned bones. Super glue helped to stabilize the rods. To these pins were affixed Polhemus Fastrak™ electromagnetic sensors capable of collecting positional information with 6 degrees of freedom. In addition, translational movements of the first metatarsal were measured using a stylus sensor that was placed at its base and head.

The feet were then secured to a custom made loading frame with 7 pneumatic cylinders used to apply tensile forces to the extrinsic muscle tendons and a single compressive cylinder that was attached to the tibia/fibula. The design of the attachment allowed a physiological distribution of weight (85% to the tibia and 15% to the fibula). The tendon clamps were attached to the remaining pneumatic cylinders via nylon cords. A Pedar™ insole, placed under the loaded foot, measured plantar forces. The plantar force data were collected and analyzed using Novë™ software.

The feet were cyclically loaded to loosen the soft tissues surrounding the ligament attenuation sites. The extrinsic musculature was statically loaded to neutral midstance, except the TA and FHL, which were cyclically loaded to 100 N at 1 Hz for 5400 cycles.

Physiological norms of ankle joint and MTPJ angles and muscle forces were established for four phases in the gait cycle (30%, 48%, 52% and 62%). These were selected to simulate at a foot moving from midstance to toe-off; the MTPJ angle increased by approximately 10° in each of these phases. The ankle and MTPJ were manipulated by a custom-designed support that allowed the heel to be wedged at different heights and the toes to be dorsiflexed appropriately. All balanced muscle forces were normalized to one-eighth body weight.

Once the foot was loaded correctly for a particular part of the gait cycle, balanced information was collected about the bone orientation and the plantar forces. The following conditions were then randomly applied to each neutral phase in the gait cycle:

Condition 1: Overpull of FHL
Condition 2: Overpull of TA and underpull of PL
Condition 3: Overpull of FHL and TA and underpull of PL

Overpulls were simulated as 100 N forces and underpulls as 0 N. After the imbalanced condition was allowed to equilibrate, static measurements of bone position and plantar force were taken.

Results:
Data were analyzed using linear mixed effects models. The dependent variables were the differences in angles, peak forces and movement from the corresponding neutral phase of gait. Independent variables were imbalance type. Tests for mean differences for individual overpull types and post-hoc pairwise comparisons among overpull types were considered significant if p < 0.01. Data are reported as mean (standard deviation).

Overall, there were significant differences for the unbalanced conditions relative to the balanced conditions, including increased forces under the halluc, decreased forces under the first metatarsal head, plantar flexion of the halluc, dorsiflexion of the medial cuneiform and increased MTPJ stiffness. Relative to the balanced condition, Condition 1 demonstrated increased plantar force under the halluc by 11.3 N (4.2 N) and decreased plantar force under the head of the first metatarsal by 5.4 N (2.8 N). Condition 2 showed decreased force under the first metatarsal head by 7.5 N (3.6 N), plantar flexion of the halluc by 5.9° (4.0°) and dorsiflexion of the first metatarsal relative to the medial cuneiform by 1.1° (0.8°). Condition 3 elicited increased force under the halluc by 8.9 N (4.9 N), decreased force under the first metatarsal head by 9.1 N (4.4 N), plantar flexion of the halluc 5.1° (6.1°), a dorsiflexed first metatarsal relative to the medial cuneiform by 0.6° (0.7°) and increased MTPJ stiffness. The first metatarsal, however, did not show significant translation upwards.

Discussion:
The different imbalances demonstrated changes in the first ray structure that were consistent with the formation of a dorsal bunion, especially in Condition 3, which involved all the imbalances. Plantar forces showed increased values under the halluc and decreased forces under the first metatarsal head. The medial cuneiform showed the expected dorsiflexion and there was a small, but significant change in the angle between the first metatarsal and the medial cuneiform. Additionally, the halluc demonstrated plantar flexion in Condition 2 and Condition 3. At each part of the gait cycle, there were increased halluc plantar forces for the Condition 1 and Condition 3. Greater force under the toe at a given angle demonstrates a stiffer MTPJ, but it was only significant for Condition 3. In short, Condition 3 showed trends most consistent with the formation of a dorsal bunion. It was hypothesized that some of the upward movement of the first metatarsal at the MTPJ could be caused by translational motion of the first metatarsal, rather than pure rotational changes. However, statistical analysis demonstrated that rotational movements were limited.

Further exploration will be aimed at surgical corrections of the dorsal bunion. For instance, the efficacy of osteotomies and tendon transfers could be assessed by analyzing in the same manner as described in the model. Then, the surgical procedure of interest could be performed and this model repeated. Repeated measures analysis would highlight differences between the uncorrected foot and the corrected foot.

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References: