INTRODUCTION
Split tendon transfers of tibialis anterior (TA) or tibialis posterior (TP) are commonly performed to correct varus deformity of the hindfoot in patients with cerebral palsy, stroke, and brain injury. Both of these procedures involve detaching half of the tendon from its medial insertion and reattaching laterally such that the muscle acts as a balanced yoke that neither inverts nor everts the foot [1,2]. Clinical results for these procedures have been generally good but highly variable; some surgical failures have been attributed to difficulties in achieving a proper balance of tension between the tendon halves [2]. The effect of variation of the lateral insertion site of TA was investigated in a previous cadaver study, but changes in muscle moment arms resulting from the procedure were not measured [3]. Knowledge of subtalar joint moment arms is important for understanding how the inverting action of the muscle is changed following surgery, and how its function depends on joint angle. The goal of the present study was to measure subtalar joint moment arms of TA and TP before and after split tendon transfer.

METHODS
Five fresh-frozen lower leg cadaver specimens (72 - 89 y; 4 female, 1 male) were sectioned approximately 23 cm above the plantar surface of the foot and TA and TP were identified. The specimens were left intact below a transverse plane 5 cm superior to the malleoli; soft tissues above this level were removed. Each specimen was secured to a foot plate by two steel pins inserted medially-laterally through the posterior calcaneus, a screw driven into the inferior aspect of the calcaneus, and taping of the forefoot. This foot plate was mounted in a six-degree-of-freedom testing apparatus that could be moved freely with respect to the base of the jig or locked rigidly in place. The proximal end of the sectioned tibia was rigidly fixed to the testing apparatus using a bolt inserted into the intramedullary canal and secured with a Steinmann pin and bone cement. Steel cables (0.5 mm dia.) were sutured to the distal tendons of each muscle at the level of the musculotendinous junction. These cables were passed through pulleys such that physiological lines of action were reproduced. Cable transducers (Celesco PT101) applied a constant tension of 7.5 N to each tendon and measured tendon excursions to within ±0.025 mm. The talocural joint was fixed in neutral position by screws driven through the medial malleolus and talus.

Subtalar joint angle was measured using an instrumented spatial linkage (ISL) [4] which was connected to the movable foot plate and the fixed base of the test device. Base-to-plate transformations were computed from ISL potentiometer voltages during trials in which the foot was manually inverted and everted. The subtalar joint was assumed to be cylindrical and an optimization technique was used to compute its joint axis. Subtalar joint angle was computed using an Euler angle decomposition of the base-to-plate transformation. A static trial taken in anatomical position provided a reference for which the subtalar angle was assumed to be zero.

Tendon excursion data from six inversion-eversion trials were averaged and this average was fit with a 4th-order polynomial. Moment arms were computed as the derivative of the tendon excursion polynomial with respect to joint angle [5]. Split transfer of TA and TP were performed according to the published techniques [1,2]. Tendon excursion measurements were repeated following the tendon transfers. Two-way ANOVAs followed by multiple comparisons were used to test the effects of subtalar joint angle (-5º, 0º, 5º, 10º, and 15º; inversion positive) and surgical condition (intact and split transferred) upon both TA and TP moment arms.

RESULTS
Average moment arm data (n = 5) for TA and TP under each surgical condition are presented in Figures 1 and 2, respectively. Results for intact moment arms agreed with previously reported values measured using a similar technique [6]. Two-way ANOVA indicated that split transfer reduced the inversion moment arm of TP (P = 0.013), converting the muscle into an evertor when the foot was inverted by more than 5º. A significant interaction was found between surgical condition and joint angle for TA; multiple pairwise comparisons indicated that inversion moment arms were reduced at only the three most inverted positions (all P-values <= 0.026).

DISCUSSION
These preliminary results indicate that split tendon transfers of TA and TP have the intended effect of reducing the effective inversion moment arm, even reversing its direction when the foot is inverted. Reduction of the inversion moment arm of TP evident in eversion, however, may contribute to overcorrection of varus deformity. Measurement of moment arms greater than zero in neutrally-positioned specimens indicated that an imperfect balancing of the yoke was achieved; such imbalances may lead to undercorrection in extreme cases.

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REFERENCES

Figure 1. Mean subtalar joint moment arms (n = 5) for intact and split transferred TA. Error bars indicate one standard deviation.

Figure 2. Mean subtalar joint moment arms (n = 5) for intact and split transferred TP. Error bars indicate one standard deviation.