MEDIAL LONGITUDINAL ARCH MOTION AND THE WINDLASS EFFECT DURING GAIT USING A MULTI-SEGMENT FOOT MODEL

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INTRODUCTION

Current gait analysis practice treats the foot as a single rigid segment and is therefore unable to measure clinically important motion of the joints of the foot. Several multi-segment foot models have been developed to address this deficiency [1,2]. This study uses a multi-segment foot model to examine the behaviour of the medial longitudinal arch and the hallux during normal level walking. The movement of these structures has had limited study [3] due to the difficulties in tracking six degree of freedom motion of the required segments in vivo. However, there has been much speculation on the role of the medial longitudinal arch and the windlass effect of the dorsiflexing hallux, and how these structures allow the foot to transition from a flexible and compliant structure in early stance to a rigid lever in late stance. However, this has yet to be clearly demonstrated in a large population in vivo.

Since much of the clinical practice in podiatrics and pedorthics presumes this behaviour, it seems important that this assumption be validated. Proper characterization of normal arch function and its disruption due to pathology would improve clinical understanding and treatment.

METHODS

One subject (age 26, weight 85.5 kg, height 82.5 cm) with no prior history of foot or ankle problems performed level barefoot walking at self-selected pace. 3D kinetic and kinematic data were collected with a Helen Hayes full body marker set and a multi-segment right foot marker set (Motion Analysis Corp). The foot was functionally divided into six rigid segments: talus, hindfoot, midfoot, medial and lateral forefoot and the hallux. Each segment (except for the talus) was tracked in six degrees of freedom with a three marker cluster (marker diameter 8mm, separation 24mm, carbon-fiber stalks, 16mm delrin base).

11 bony landmarks were digitized during an initial static trial and tracked during walking. Three are used in this study: lateral distal calcaneus (CL), navicular tuberosity (NT) and lateral eminence of the 1st metatarsal head (M1). The length (L) of the medial longitudinal arch is defined as the distance from CL to M1. The height (h) of the arch is the perpendicular distance from NT to the arch length vector. The ratio h/L was found and normalized to 1.0 in quiet standing. Dorsiflexion/plantarflexion of the hallux was defined as the angle of the long axis of the hallux segment with respect to the shaft of the 1st metatarsal. This approximately to 180° in quiet standing. Decreasing angle represents dorsiflexing motion.

RESULTS

The medial longitudinal arch was shown to be flatter and longer in early stance and higher and shorter in late stance (Figure 1). An unexpected small rise in the arch was seen between 10% and 40% stance. The hallux was found to be equally dorsiflexed early and late in stance and more neutral from 20% to 70% stance (Figure 2).

DISCUSSION

Early in stance, the arch was low and long but the hallux was dorsiflexed as much as in late stance. This likely represents the activity of the extensor hallucis longus acting to dorsiflex the ankle between heel strike and foot flat. In terminal stance during toe-off, the arch was found to be high and short with the hallux dorsiflexed. The hallux is likely acting as a windlass to tighten the plantar fascia and stabilize the arch as has been previously speculated. The lower peak in the h/L ratio of the arch between 10% and 40% stance was unexpected and deserves further study to determine its clinical significance.

REFERENCES

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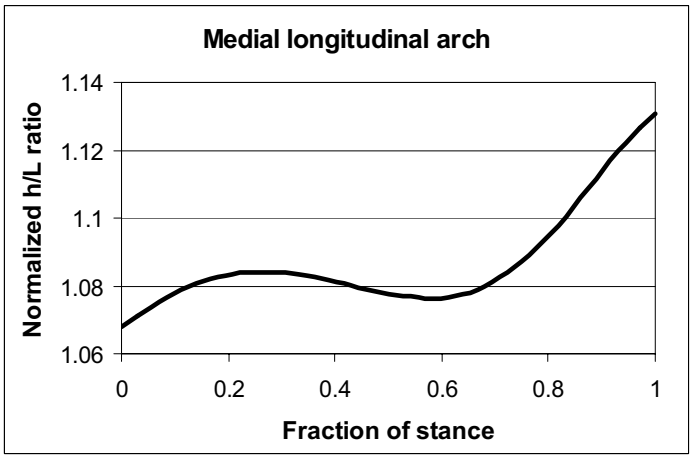

Figure 1: Normalized h/L ratio of the medial longitudinal arch shows the arch is raised higher and shorter than quiet standing. The arch showed an unexpected low peak in height early in stance and then the expected high peak in height in late stance.

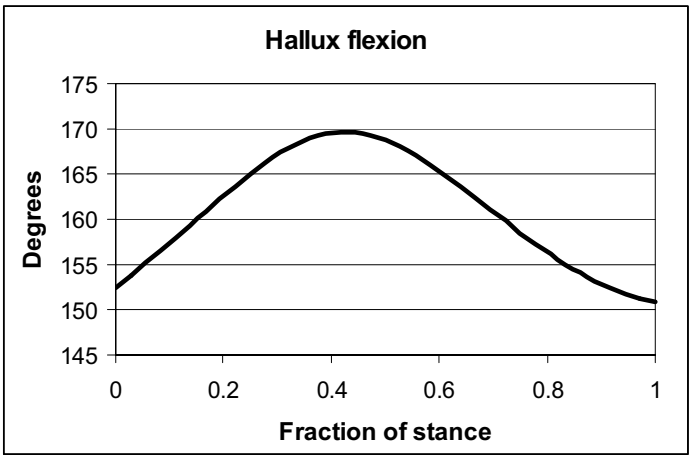

Figure 2: Hallux flexion angle in the sagittal plane where 180° defines the hallux in line with the 1st metatarsal and smaller angles represent dorsiflexion. Note the equal amounts of dorsiflexion early and late in stance, with more neutral positioning in midstance.