# IN VITRO STUDY OF FOOT KINEMATICS USING A WALKING SIMULATOR

[1] Anmin Liu, [1]Chris Nester, [2]Erin Ward, [1]David Howard, [2]Jay Cocheba, [2]Tim Derrick, [2]Pat Patterson.
[1]Centre for Rehabilitation and Human Performance Research, university of Salford,
[2] Dept. Engineering and Dept Health and Human Performance, Iowa State University.
email: c.j.nester@salford.ac.uk , web: www.healthcare.salford.ac.uk/crhpr

## INTRODUCTION

Previous published descriptions of foot and ankle kinematics are incomplete because they are selective in their location of measurement devices on the foot. There is a particular dearth of information on navicular, cuboid, cuneiform and metatarsal kinematics. We aimed to describe the kinematics of the tibia, talus, calcaneus, navicular, cuboid, three cuneiforms, five metatarsals and proximal phalanx of the hallux during a cadaver based simulation of walking.

## METHODS

A dynamic cadaver model (walking simulator) was used to apply load to the tibia and leg tendons in a manner to move the specimen in a manner similar to walking. The walking simulator consists of a rigid metal frame supported by four wheels, which is pulled along a track by a motor and cable. Attached to the frame is a pneumatic cylinder which applies vertical load to the below knee cadaver specimen. Artificial muscle forces are applied through attachments to nine individual tendons (tibialis posterior, tibialis anterior, flexor hallucis longus, flexor digitorum longus, Achilles, peroneus brevis, peroneus longus, extensor digitorum longus and extensor hallucis longus) using eight motors (extensor hallucis and digitorum longus are tied together). The tibial loading, forward progression of the tibia and tendon force actuators are open loop controlled and adjusted manually. The duration of stance is approximately 2 seconds and ends prior to toe off, at about 80% of normal stance. Data were collected on 13 specimens (age 32 to 80). Clusters of 4 reflective markers were attached to each bone using 1.6mm K wires.

Eular angles were computed for 22 anatomical joints. To assess the repeatability of the walking simulation, the coefficient of multiple correlation (CMC) was calculated for the kinematic data and ground reaction forces.

## RESULTS AND DISCUSSION

The simulator produced repeatable simulations of gait for each foot. CMC for the major rearfoot joints (ankle, sub talar, talonavicular and calcaneo cuboid joints) were all > 0.6. Table 1 shows mean range of motion at each joint during the simulated stance phase (mean of 13 feet). The kinematic pattern at the ankle and sub talar joints was in line with in vivo kinematic data [1]. We found greater frontal and transverse plane motion at the talonavicular joint (mean of 11.6° and 15.5° respectively) than at the calcaneocuboid joint (mean of 5.9°, 6.8° respectively). The concept of the 'mid tarsal' joint, at which the navicular and cuboid move as a single functional unit relative to the calcaneus and talus, is broadly supported by the data. Whilst there was relative motion between the navicular and cuboid, both joints dorsiflexed during the first 60% of the simulated stance phase, and plantarflexed thereafter. Both joints everted and abducted during the first 30% of the simulated stance phase, and inverted and adducted thereafter.

The motion between the cuneiforms and navicular, and the cuboid and cuneiforms was greater than we had anticipated At the medial cuneiform/navicular joint there was on average 9.8°, 6.5° and 3.1° in the sagittal, frontal and transverse planes respectively. The motion between metatarsals 4 and 5 and the cuboid was consistently larger than the motion between the other metatarsals and their cuneiforms. Metatarsals 1-3 moved an average of just 4.7° and 5° in the sagittal and frontal planes relative to the cunieforms, whereas metatarsals 4 and 5 moved 9.8° and 9° respectively in relation to the cuboid.

Our data demonstrate that all mid and forefoot joints have an important role in the overall kinematic function of the foot. For example, based on the mean data sagittal plane motion between the navicular and talus, navicular and medical cuneiform, and medial cuneiform and the first metatarsal, totaled 23.9° during the part of stance simulated. This is comparable to the motion at the ankle and sub talar joints. The motion between the cuneiforms and navicular (9.8°, 8.5° and 10.5° for the medial, central and lateral cuneiforms respectively in the sagittal plane) was comparable to, or in some cases exceeded, the motion between the talus and navicular (9.6°) and between the calcaneus and cuboid (6.9°).

## REFERENCES

1. Arndt et al. Foot & Ankle. 2004. 25: 5: 357-364.

## ACKNOWLEDGEMENTS

This project was funded by the UK EPSRC

| | Calc-Tib | Tal-Tib | Calc-Tal | Nav-Tal | Cub-Calc | Mcun - Nav | Ccun - Nav | Lcun - Nav | Lcun-Ccun | Ccun-Mcun | Cub-Lcun | Cub - Nav |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sag | 23.5 | 21.4 | 5.5 | 9.6 | 6.9 | 9.8 | 8.5 | 10.5 | 5.2 | 4.4 | 8.2 | 6.0 |
| Front | 11.9 | 12.4 | 8.4 | 11.6 | 5.9 | 6.5 | 6.3 | 5.8 | 4.7 | 3.4 | 5.4 | 6.3 |
| Trans | 7.8 | 7.9 | 6.0 | 15.5 | 6.8 | 3.1 | 3.7 | 6.8 | 3.3 | 3.1 | 3.7 | 5.4 |

| | Met1 - Mcun | Met2 - Ccun | Met3 - Lcun | Met4 - Cub | Met5 - Cub | Met2 - Met1 | Met3 - Met2 | Met4 - Met3 | Met5 - Met4 | PrxP-Met1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sag | 4.5 | 4.4 | 5.2 | 9.7 | 9.9 | 5.1 | 3.4 | 4.3 | 5.0 | 40.4 |
| Front | 5.6 | 3.6 | 6.0 | 7.2 | 10.8 | 5.4 | 4.4 | 6.2 | 7.0 | 14.2 |
| Trans | 4.3 | 3.4 | 3.9 | 4.2 | 4.4 | 3.6 | 2.2 | 2.8 | 3.4 | 15.0 |

Table 1. Mean (of 13 feet) total range of motion at each of the joints