INTRODUCTION

The center of pressure (COP) movement has been identified as a measure of neuromuscular control during posture and gait. Defined as the centroid of all the external forces acting on the plantar surface of the foot, the COP has further been used to identify balance control, foot function, and treatment efficacy [1].

As patients with lower limb dysfunction often demonstrate modified gait patterns, it would be beneficial to characterize COP trajectories over a variety of possible foot strike conditions. Previous studies have demonstrated the effectiveness of orthoses in reducing the COP mediolateral movement among patients with forefoot valgus and forefoot varus [2], though no studies have demonstrated the expected COP trajectory across stance for a variety of foot postures during gait.

Knowledge of the proper COP trajectory can provide clinicians with proper diagnosis of foot pathology and treatment intervention. Therefore the purpose of this study was to investigate the COP movement when walking under normal and modified gait conditions.

METHODS

A total of 13 healthy young adults (8 females, age 25.1 ± 2.9 years), were asked to walk barefoot across an 8 meter walkway under four conditions: 1) plantigrade; 2) equinus; 3) inverted; and 4) everted walking. During equinus, inverted, and everted walking, subjects ambulated on their toes, lateral borders of their feet, and medial borders of their feet, respectively, in order to simulate walking with a pathology. All participants provided written informed consent prior to involvement in the study. The study protocol was approved by the Mayo Clinic Institutional Review Board.

Three-dimensional trajectories of 12 reflective markers bilaterally placed on the feet were collected using a 10-camera motion analysis system (Motion Analysis Inc., Santa Rosa, CA). Ground reaction forces and moments were collected from three force plates (AMTI Inc., Watertown, MA). Kinematic and kinetic data was collected at 120Hz and 720Hz, respectively. Foot anthropometrics including navicular height, foot length and foot width. The arch index was calculated during loaded conditions based on the ratio of navicular height and foot length [3].

The COP was computed for each limb throughout stance from the measured ground reaction forces and moments. The COP was converted into the foot coordinate system, with data normalized in the anterior-posterior and medial-lateral direction based on the foot length and foot width, respectively. Differences in the COM range of motion (ROM) across walking conditions was evaluated using a one-way ANOVA. A comparison of loaded foot arch index and the COP ROM was performed using a Pearson’s correlation.

RESULTS AND DISCUSSION

A total of 26 feet were evaluated across all four walking conditions, with the COP traversing the forefoot, lateral boundary, and medial boundary of the foot during the three pathological gait conditions (Fig. 1). On average, the COP remained along the midline, the lateral portion, and the medial portion of the foot, during midstance for plantigrade, inverted and everted walking, respectively (Fig. 2). Towards end of stance, the COP progressed to the lst metatarsal-phalangeal joint for all conditions.
Figure 1: Representative trajectories of the COP for the right foot during plantigrade, equinus, inverted, and everted walking.

Figure 2: Excursion of the COP over the four walking conditions. Each point represents 5% of stance. Gray bands represent ± 1 SD.

Participants demonstrated a significant condition effect for both the anterior-posterior and medial-lateral COP ROM (Fig 3; P < 0.001). The equinus walking condition demonstrated differences from all other conditions (P < .001), with the COP traversing across approximately 26% of the foot length and 41% of the foot width. The inverted walking condition also demonstrated a 10% greater COP ROM in the medial-lateral direction than everted walking (P = 0.036).

The arch index was not correlated with the COP ROM for any measure except for the anterior posterior COP ROM during inverted walking (R² = 0.31; P = 0.008).

Results of the COP ROM are similar to those reported previously, in which the COP displacement corresponded to 83% of foot contact length and 18% of foot contact width [4]. During midstance, foot placement affected the COP by up to 10% in the medial-lateral direction, revealing mechanisms for further complications. During pathological walking, balance ability and joint loading are affected, as the center of mass acceleration and lower extremity torques are altered by COP position. Investigation of the COP trajectory among patients is therefore crucial for proper intervention.

Figure 3: COP range of motion across four conditions. The central dashed line represents the median, the box edges are the 25th and 75th percentiles, and the whiskers extend to ± 2.7 SD. Outliers are labeled as +.

REFERENCES

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