Gait & Posture 59 (2018) 7–10

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Short communication

Concurrent validity of an automated algorithm for computing the center of pressure excursion index (CPEI)

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ARTICLE INFO

Keywords:
Center of pressure excursion index
CPEI
Foot function
Gait analysis
Plantar pressures

ABSTRACT

Center of Pressure Excursion Index (CPEI), a parameter computed from the distribution of plantar pressures during stance phase of barefoot walking, has been used to assess dynamic foot function. The original custom program developed to calculate CPEI required the oversight of a user who could manually correct for certain exceptions to the computational rules. A new fully automatic program has been developed to calculate CPEI with an algorithm that accounts for these exceptions. The purpose of this paper is to compare resulting CPEI values computed by these two programs on plantar pressure data from both asymptomatic and pathologic subjects. If comparable, the new program offers significant benefits—reduced potential for variability due to rater discretion and faster CPEI calculation. CPEI values were calculated from barefoot plantar pressure distributions during comfortable paced walking on 61 healthy asymptomatic adults, 19 diabetic adults with moderate hallux valgus, and 13 adults with mild hallux valgus. Right foot data for each subject was analyzed with linear regression and a Bland-Altman plot. The automated algorithm yielded CPEI values that were linearly related to the original program ($R^2 = 0.99$; $P < 0.001$). Bland-Altman analysis demonstrated a difference of 0.55% between CPEI computation methods. Results of this analysis suggest that the new automated algorithm may be used to calculate CPEI on both healthy and pathologic feet.

1. Introduction

Aberrant foot biomechanics is implicated in foot pathologies and injuries [1–5]. Objective and reliable functional foot assessment is critical to elucidate pathomechanics and to improve management of foot pathologies. The Center of Pressure Excursion Index (CPEI) is a measure of dynamic foot function during the stance phase of gait [6]. It has been used in a number of investigations evaluating foot biomechanics in planus, rectus, and cavus foot types in healthy subjects as well as subjects with certain foot pathologies [7–11].

CPEI assesses the concavity of the center of pressure curve from heel strike to toe-off, and can be a useful parameter in clinical evaluation. Smaller values are associated with more medially directed ground reaction forces which suggest overpronation, while larger values are associated with more laterally directed ground reaction forces, which suggest oversupination. In asymptomatic feet, CPEI could be used to delineate individuals who may benefit from pronatory control athletic shoes. In pathologic cases (e.g. posterior tibial dysfunction) CPEI could describe the state of over pronation both pre and post-intervention which would let the treating clinician evaluate the efficacy of treatment.

The original custom-developed C + + program was used to facilitate the CPEI calculation and provide the rater an opportunity to adjust parameters of the algorithm to account for unusual dynamic plantar loading, see Fig. 1 [6]. Some common exceptions to the rule for calculating CPEI have been identified, see Fig. 2 [12]. These conditions, which had to be accounted for with user interaction in the original custom program, were incorporated into the new automated software, the CPEI-(H) program within the Gaitline and Geometry analysis packages (novel Gmbh, Munich). The purpose of this study is to compare the CPEI values calculated from the original and new programs. If the new automated program yields comparable results to the original as evaluated by linear regression analysis ($R > 0.7$; $p < 0.05$), CPEI may be calculated more efficiently by eliminating the requirement of user interaction and ensuing variability due to multiple raters.

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http://dx.doi.org/10.1016/j.gaitpost.2017.09.022
Received 3 January 2017; Received in revised form 15 September 2017; Accepted 20 September 2017

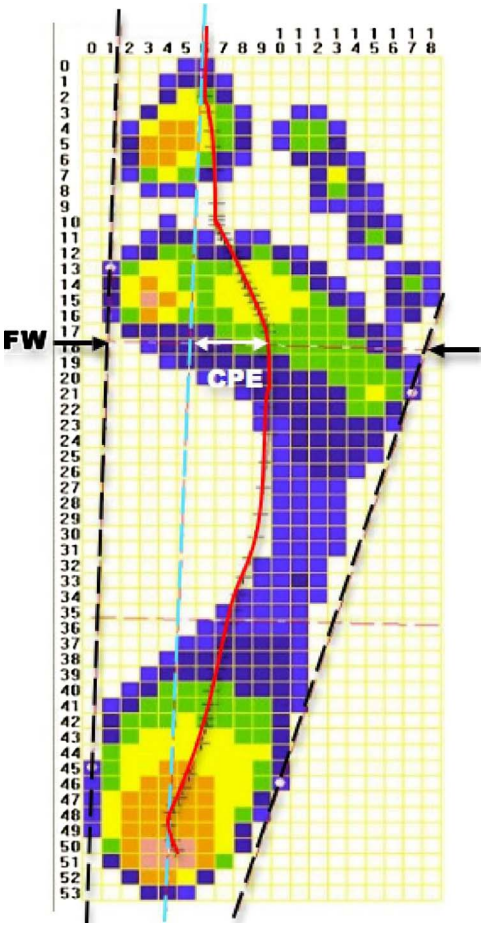

Fig. 1. Calculation of CPEI without any exceptions. Medial and lateral foot borders are illustrated as black dashed lines. A construction line from the initial to final COP point is shown in light blue dashes while the COP curve is outlined in red. Both Foot Width (FW) and Center of Pressure Excursion (CPE) are measured along the first anterior trisection of the foot as indicated (CPEI(%) = 24.4). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Participants

Three different subject groups were included in this analysis—one group of asymptomatic healthy adults, and two groups containing forefoot pathologies. Data was previously collected by researchers at the Leon Root, MD Motion Analysis Laboratory at the Hospital for Special Surgery on 61 asymptomatic healthy adults between the ages of 18 and 77 [10]. Dynamic plantar pressure distributions were collected using novel emed-X (4 sensors/cm^2, at a sampling rate of 100 Hz) while participants walked at their self-selected comfortable walking speed while barefoot. The next group of subjects included 19 diabetic adults with moderate hallux valgus, collected at the Temple University School of Podiatric Medicine (TUSPM). The third group of subjects included 13 symptomatic adults between the ages of 23 and 61 with mild hallux valgus confirmed on X-Ray, also collected at TUSPM. It has been determined that an average of five walking trials, using a mid-gait protocol, offers a reliable unbiased estimate of the mean of each plantar pressure parameter for a given foot [13]. Thus, five trials (right feet only) per subject for all 93 subjects were analyzed.

2.2. Calculations of CPEI

For each trial, CPEI was calculated independently using both the original and the fully automated novel program. All calculations in the original software were completed by the same experienced rater. The average CPEI of the five trials for each foot was computed separately for both methods.

In the original software, the medial and lateral borders of the foot and anterior to posterior trisections are defined based on the maximum pressure throughout the stance phase plot, see Fig. 1 [6]. The line passing through the most medial hindfoot and forefoot regions, excluding toes, is defined as the medial border of the foot. The line passing through the most lateral hindfoot and forefoot regions, excluding toes, is defined as the lateral border of the foot. The direction of progression is assumed parallel to the long axis of the plantar pressure measuring device. Foot length and the anterior trisections are drawn perpendicular to the medial long axis. A construction line from the initial to final Center of Pressure (COP) value is drawn. CPEI is defined, in percent, as the ratio of the distance from the COP to the construction line (center of pressure excursion (CPE)) and the foot width (FW) at the anterior third of foot length.

$$\text{CPEI}(\%) = (\text{CPE}/\text{FW}) * 100 \quad (1)$$

Rules and Exceptions: Fig. 2 illustrates several scenarios where human raters could adjust the search algorithm to select appropriate landmarks [12]. When the COP pattern exhibits a heel to toe trajectory without any aberrations, the construction line is not adjusted (Fig. 2A). Landing on the lateral heel and rapidly everting medially biases the COP construction line, resulting in smaller CPEI values (Fig. 2B). This can be corrected by advancing the origin of the construction line to the most medial value within the posterior trisection. When a subject has an anatomical deviation (e.g., Morton's 2nd toe causing the COP to reverse direction in the propulsion phase of stance with minimal loading), the final point defining the construction line should be moved back to the most medial value within the anterior trisection (Fig. 2C). If the COP curve does not exhibit a heel to toe gait pattern with an initial point anterior to the posterior trisection, such as in an equinus gait, CPEI cannot be computed (Fig. 2D). Note that CPEI is only applicable to barefoot measurements.

In the automated novel software, the foot axis is defined with respect to the bisection of the plantar angle. Foot length is determined by measuring the overall length of the footprint from a line that is parallel to the plantar angle, not the long axis of the pressure-measuring device. Foot length and anterior trisections are drawn to be perpendicular from the medial border of the footprint. The lateral and medial borders are then defined using the same rules as in the custom program. The construction line is defined at its most medial point within the posterior third of the footprint to correct for initial pronation or most medial point within the anterior third in the case of a Morton's 2nd toe. CPEI (%) is then calculated from equation 1 above.

2.3. Statistical analysis

The average CPEI for five right footprints per subject was calculated in the original and new programs. SPSS (version 22, IBM, NY) was used to perform a linear regression of CPEI from the automated versus original program to support the association between these computational methods employing all 93 subjects—asymptomatic healthy, diabetic with moderate hallux valgus, and those with mild hallux valgus—as one cohort. Since this association is necessary, but not sufficient for establishing agreement, a Bland-Altman analysis was performed on all 93 subjects (right feet only).

3. Results

The original program with human oversight yielded an average CPEI value for all 93 subjects (right feet only) of 20.11% with a standard deviation of 6.32%. The new automated algorithm provided an average CPEI value for all 93 subjects of 19.56% ± 6.40%. A linear