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Centre of pressure characteristics during walking in individuals with and without first metatarsophalangeal joint osteoarthritis

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ABSTRACT

Objective: The objective of this study was to compare centre of pressure characteristics during walking in individuals with and without first metatarsophalangeal joint osteoarthritis (1st MTPJ OA), in order to provide insights into alterations in foot function associated with this condition.

Methods: Twenty people with 1st MTPJ OA and 20 asymptomatic controls matched for age, sex and body mass index underwent gait analysis using the emed^x-x400 plantar pressure system (Novel GmbH, Germany). Average and maximum centre of pressure velocity and lateral-medial force index during loading, midstance, terminal stance and preswing were compared between the groups.

Results: During the preswing phase of gait, maximum centre of pressure velocity was significantly slower in individuals with 1st MTPJ OA (0.78 ± 0.19 vs 1.13 ± 0.36 m/sec; $p = 0.003$), and both average and maximum lateral-medial force indices were significantly higher in individuals with 1st MTPJ OA (0.98 ± 0.14 vs 0.82 ± 0.13 ; $p < 0.001$ and 1.37 ± 0.29 vs 1.15 ± 0.15 ; $p = 0.008$, respectively). Non-weightbearing 1st MTPJ dorsiflexion range of motion was significantly associated with maximum centre of pressure velocity ($r = 0.54$, $p < 0.001$) and average lateral-medial force index ($r = -0.44$, $p = 0.004$) during preswing.

Conclusions: Individuals with 1st MTPJ OA exhibit significant differences in centre of pressure characteristics during propulsion, possibly due to decreased range of available 1st MTPJ dorsiflexion.

1. Introduction

Osteoarthritis of the first metatarsophalangeal joint (1st MTPJ OA) is a common and disabling condition which affects 8% of people aged over 50 years [1]. The condition is characterised by symptoms of joint pain and stiffness, formation of a dorsal exostosis, and progressive reduction in range of motion of 1st MTPJ dorsiflexion [2]. Because the 1st MTPJ plays an important role in transferring the body's centre of mass over the foot during the propulsive phase of gait [3], individuals with 1st MTPJ OA frequently adopt an aporulsive walking pattern [4], which is associated with locomotor disability and decreased health-related quality of life [5].

Several studies have been undertaken to examine the effect of limited 1st MTPJ motion on foot biomechanics, with equivocal findings. While some kinematic studies have reported a significant reduction in maximum 1st MTPJ dorsiflexion [4], others have found no difference [6]. Similarly, three plantar pressure studies have reported increases in pressure under the hallux and lesser toes in individuals with hallux rigidus [7–9], while a more recent analysis has suggested that people

with 1st MTPJ pain adopt an antalgic gait pattern which decreases loading under the hallux [10]. The inconsistency apparent in the literature is likely due to different measurement protocols and case definitions of the disorder. However, it could also be argued that the gait parameters selected in these previous studies may not be indicative of the aporulsive gait pattern commonly observed with this condition.

The centre of pressure pattern during walking, also referred to as the 'gait line', was first described in 1939 [11]. When measured with a plantar pressure platform, the centre of pressure can be determined by calculating the centroid of the total number of active sensors for each data sample collected [12]. The temporal and spatial characteristics of the centre of pressure provide a global measure of how load is distributed through the foot when walking, and may provide insights into how effectively bodyweight is transferred during propulsion [12,13]. Previous studies have shown that centre of pressure velocity is decreased in older individuals [14] and individuals who have had their toes amputated [15], while centre of pressure velocity is increased in response to wearing shoes with a metatarsal bar to aid propulsion [16]. As such, the centre of pressure may provide useful insights into the

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effect of 1st MTPJ OA on foot function during propulsion.

Therefore, the primary objective of this study was to compare centre of pressure characteristics during walking in individuals with and without 1st MTPJ OA. Specifically, we were interested in comparing both the velocity of the centre of pressure and the magnitude of force generated lateral and medial to the centre of pressure during propulsion. The secondary objective was to determine whether these variables were influenced by the available range of passive non-weightbearing dorsiflexion range of motion of the 1st MTPJ.

2. Methods

2.1. Participants

Twenty individuals with 1st MTPJ OA were recruited from a larger randomised trial assessing the effectiveness of rocker-sole footwear and prefabricated foot orthoses for this condition [17]. Key inclusion criteria were: (i) > 18 years of age, (ii) pain in the 1st MTPJ on most days for at least 12 weeks, (iii) pain rated at least 20 mm on a 100 mm visual analogue scale, (iv) less than 64° of passive non-weightbearing dorsiflexion range of motion of the 1st MTPJ [18], and (v) pain upon palpation of the dorsal aspect of the 1st MTPJ.

Twenty control participants were matched to the 1st MTPJ OA group for age, sex and body mass index. Key inclusion criteria for the control group were (i) > 18 years of age and (ii) no history of musculoskeletal pain/symptoms in both lower limbs for the previous year. Key exclusion criteria for both the 1st MTPJ OA and control groups included: (i) pregnancy, (ii) previous surgery on the 1st MTPJ, (iii) significant deformity of the 1st MTPJ including hallux valgus [19,20], (iv) other conditions within the foot or ankle such as metatarsalgia, plantar fasciitis, pre-dislocation syndrome, Achilles tendinopathy and degenerative joint disease, (v) any systemic inflammatory condition, and (vi) cognitive impairment.

Both 1st MTPJ OA and control participants were recruited between March and November 2015. The La Trobe University Human Ethics Committee provided ethical approval (number FHEC13_196) and all participants provided written informed consent prior to enrolment.

2.2. Clinical and radiographic assessment

Participants underwent a clinical assessment including measurements of height, weight and body mass index, foot posture (using the Foot Posture Index [21]), and passive non-weightbearing dorsiflexion range of motion of the 1st MTPJ using a flexible plastic hand-held goniometer [22,23]. The reliability of this test has been shown to be excellent in healthy individuals [23] and individuals with 1st MTPJ OA [18] (intra-class correlation coefficient = 0.95).

In the 1st MTPJ OA group, characteristic clinical features (pain on palpation, dorsal exostosis, joint effusion, pain on motion, hard-end feel and crepitus) were documented [18], and the presence of radiographic changes was determined using a standardised radiographic atlas with good to excellent intra- and inter-rater reliability for grading 1st MTPJ OA (κ range 0.64–0.95) [24]. Obtaining radiographs from control participants was not considered to be justifiable. However, our previous study on clinical diagnosis of 1st MTPJ OA would suggest that the likelihood of radiographic changes in our control group would be very low, due to the absence of pain and deformity and their normal range of 1st MTPJ dorsiflexion [18].

2.3. Biomechanical assessment

Plantar pressure data were collected using the emed[®]-x400 plantar pressure system (Novel GmbH, Germany), a 700 mm long by 403 mm wide platform incorporating 6080 capacitance transducer sensors (4 sensors/cm²) sampling at a frequency of 100 Hz. The platform was embedded in a walkway and data were collected using the two-step gait

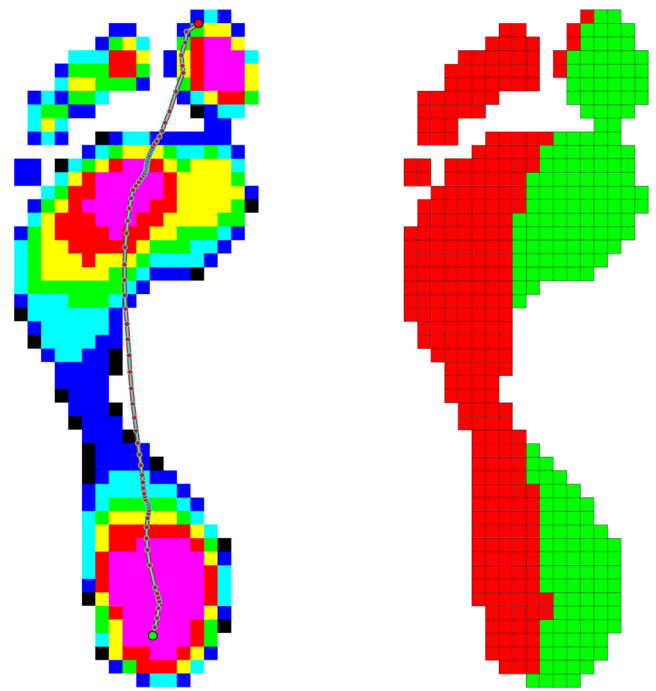


Fig. 1. Typical centre of pressure pattern obtained from the emed[®] system (left), and calculation of the lateral-medial force index (right).

initiation protocol [25], with participants instructed to walk barefoot at their normal comfortable speed. For each participant, five trials were recorded and the average was used for analysis. The emed[®] system has been shown to produce highly reliable measurements, both within and between measurement sessions [26–28]. The key parameter of interest was the centre of pressure, calculated as the centroid of the total number of active sensors for each data sample collected [12]. Two variables derived from this parameter were obtained using the Novel Scientific Medical Software, Version 23: (i) the velocity of the centre of pressure, and (ii) the lateral-medial force index (see Fig. 1).

The velocity of the centre of pressure (VCoP) was defined as the resultant displacement of the centre of pressure divided by the elapsed time between measurements [12], and was calculated using the formula:

$$VCoP(i) = \frac{d(i)}{\Delta t}$$

...where $d(i)$ = the distance the centre of pressure travels during a frame, i = current frame number ($i = 1, \dots, M$, M = number of frames) and t = duration of one frame (in this case, 10 ms as data were collected at 100 Hz).

The lateral-medial force index (LAMFI) was defined as the total force lateral to the centre of pressure divided by the total force medial to the centre of pressure for each data sample collected [13], using the formula:

$$LAMFI = \frac{FLx}{FMx}$$

...where FL = force lateral to the centre of pressure for specified frame x , and FM = force medial to centre of pressure for specified frame x .

These variables were extracted for each participant and were normalised to stance period duration. The stance period was then divided into four phases: (i) loading response (0–20%), (iii) midstance (> 20–50%), (iv) terminal stance (> 50–83%) and (v) preswing (> 83–100%) [29], and the average and maximum values for the velocity of the centre of pressure and lateral-medial force index were calculated for each phase. Contact time of the whole foot was also extracted for each participant, as it could differ between individuals with

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