Gait & Posture 37 (2013) 603–610

Contents lists available at SciVerse ScienceDirect

Gait & Posture

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

The role of foot morphology on foot function in diabetic subjects with or without neuropathy

Annamaria Guiotto [a,1], Zimi Sawacha [a,2], Gabriella Guarneri [b,3], Giuseppe Cristoferi [b,4], Angelo Avogaro [b,5], Claudio Cobelli [a,*]

[a] Department of Information Engineering, University of Padova, Via Gradenigo 6b I, 35131 Padova, Italy
[b] Department of Clinical Medicine and Metabolic Disease, University Polyclinic, Via Giustiniani 2, 35128 Padova, Italy

ARTICLE INFO

Article history:
Received 20 March 2012
Received in revised form 20 September 2012
Accepted 30 September 2012

Keywords:
Diabetic foot
Foot type
Kinematics
Plantar pressures
Three dimensional

ABSTRACT

The aim of this study was to investigate the role of foot morphology, related with respect to diabetes and peripheral neuropathy in altering foot kinematics and plantar pressure during gait. Healthy and diabetic subjects with or without neuropathy with different foot types were analyzed. Three dimensional multisegment foot kinematics and plantar pressures were assessed on 120 feet: 40 feet (24 cavus, 20 with valgus heel and 11 with hallux valgus) in the control group, 80 feet in the diabetic (25 cavus 13 with valgus heel and 13 with hallux valgus) and the neuropathic groups (28 cavus, 24 with valgus heel and 18 with hallux valgus). Subjects were classified according to their foot morphology allowing further comparisons among the subgroups with the same foot morphology. When comparing neuropathic subjects with cavus foot, valgus heel with controls with the same foot morphology, important differences were noticed: increased dorsiflexion and peak plantar pressure on the forefoot ($P < 0.05$), decreased contact surface on the hindfoot ($P < 0.03$).

While results indicated the important role of foot morphology in altering both kinematics and plantar pressure in diabetic subjects, diabetes appeared to further contribute in altering foot biomechanics. Surprisingly, all the diabetic subjects with normal foot arch or with valgus hallux were no more likely to display significant differences in biomechanics parameters than controls. This data could be considered a valuable support for future research on diabetic foot function, and in planning preventive interventions.

1. Introduction

Diabetic and neuropathic subjects (DPN) are at increased risk for ulcer development at sites exposed to repetitive, high plantar loading [1,2]. Several studies have been conducted in the last decade to investigate diabetic foot biomechanics alterations especially in term of foot kinematics and plantar pressure (PP) during gait [1,3–8]. Previous PP studies demonstrated an important correlation between the sites displaying higher PP and the presence of callosities of DPN subjects [8,9]. Stresses were found to be relatively higher and located closer to the skin surface where skin breakdown was most likely to occur [10]. Others demonstrated an association between higher peak PP and morphological foot alteration in DPN [8,11]. Ledoux et al. investigated diabetic subjects considering the structural differences between types of foot and demonstrated close relationships between foot morphological alterations and plantar ulcerations [12–14].

Several kinematics studies have compared DPN to control subjects (CS) [5,6]. Although these studies provided insight into the potential influence of diabetes on kinematics during gait, the majority of them considered the foot as a rigid segment and evaluated its motion with respect to the tibia. Only two recent studies [4,5] applied a three-dimensional (3D) multisegment foot kinematic model to evaluate DPN foot kinematics during gait, and observed significant alterations especially in DPN's forefoot triplanar angles [4,5]. It has also been shown that limited joint mobility may contribute to increased foot subsegments loading by limiting foot flexibility and restraining the forward progression of body weight during the stance phase of gait [3]. However data substantiating the causes and consequences of foot morphology on limited mobility and excessive PP in DPN is limited.

* Corresponding author. Tel.: +39 049 8277661; fax: +39 049 8277699.
E-mail addresses: annamaria.guiotto@dei.unipd.it (A. Guiotto), zimi.sawacha@dei.unipd.it (Z. Sawacha), gabriella.guarneri@sanita.padova.it (G. Guarneri), giuseppe.cristoferi@alice.it (G. Cristoferi), angelo.avogaro@unipd.it (A. Avogaro), cobelli@dei.unipd.it, claudio.cobelli@dei.unipd.it (C. Cobelli).
[1] Tel.: +39 049 8277805; fax: +39 049 8277699.
[2] Tel.: +39 049 8277662; fax: +39 049 8277699.
[3] Tel.: +39 0498213061; fax: +39 0498213062.
[4] Tel.: +39 0498213061; fax: +39 0498213062.
[5] Tel.: +39 0498212178; fax: +39 0498754179.

0966-6362/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gaitpost.2012.09.024

Table 1
Clinical and demographic characteristics and space-time data of control group (CS), diabetic non neuropathic group (NoDPN) and diabetic neuropathic group (DPN). The reported *P* values indicate the results of the comparison between the CS and NoDPN groups, the CS and the DPN groups, and the NoDPN and DPN groups (one-way Anova). A value of $P < 0.05$ was considered statistically significant (P^*).

Groups	CS		NoDN		DN		CS vs NoPN	CS vs PN	NoPN vs PN
	# or mean	SD	# or mean	SD	# or mean	SD	*P*	*P*	*P*
Subjects [#]	20		20		20				
Sex [# of males]	14		14		13		0.5	0.5	0.37
BMI [kg/m^2]	24.41	2.58	26.49	2.22	26.24	3.68	0.009*	0.074	0.776
Hypertensive disease [#]	0		8		13		0.99	1	0.94
Age [years]	59.35	4.76	62.90	5.63	60.30	9.60	0.037*	0.694	0.303
Peripheral neuropathy [#]	–	–	0		20				1
Autonomic neuropathy [#]	–	–	0		6				0.99
Diabetic retinopathy [#]	–	–	6		12				0.97
Microalbuminury [#]	–	–	2		4				0.81
Vasculopathy [#]	–	–	2		5				0.89
Vasculopathy (peripheric) [#]	–	–	0		3				0.96
Vasculopathy (TSA) [#]	–	–	11		9				0.26
Vasculopathy (coronary) [#]	–	–	4		4				0.5
Type of diabetes [#]	–	–	type1: 3, type2: 17		type1: 10, type 2: 10				type1: 0.99, type2:0.009
Hb A1c	–	–	7.48	1.36	8.12	1.57			0.0909
Years of disease	–	–	16.05	11.14	23.00	12.84			0.0723
Cavus foot [#]	26		25		28		0.41	0.68	0.76
Flat foot [#]	0		4		4		0.98	0.98	0.5
Valgus Hindfoot [#]	22		13		24		0.02*	0.67	0.99
Varus Hindfoot [#]	0		3		3		0.96	0.96	0.5
Hallux valgus [#]	11		13		18		0.69	0.95	0.87
Foot deformities [#]	12		10		17		0.31	0.88	0.95
Plantar callosity [#]	5		21		19		0.99	0.99	0.33
Gait velocity (m/s)	0.998	0.123	1.102	0.228	1.070	0.212	0.05	0.13	0.64
Stride period (s)	1.234	0.124	1.140	0.150	1.167	0.105	0.005*	0.009*	0.51
Stride length (m)	1.222	0.114	1.234	0.183	1.230	0.189	0.91	0.96	0.96
Stance period (s)	0.762	0.086	0.668	0.103	0.698	0.079	0.0002*	0.001*	0.29

The purpose of this study was to explore the relationship between foot deformities, 3D multisegment foot kinematics and PP during gait in diabetes and DPN. This was pursued by assessing in vivo 3D multisegment foot kinematics [5] and PP of both CS and diabetes subjects with and without neuropathy.

Results of this study can be used as a support to design foot orthotic devices [15,16]. Recent literature [15,16] emphasized the importance of considering both foot biomechanics and morphology when planning various foot orthotics devices in order to efficiently reduce plantar ulcer formation and avoid amputation in diabetic subjects.

2. Methods

2.1. Subjects

Subjects were recruited among the patients attending the outpatient Clinic at the Department of Metabolic Disease of the University of Padova (Italy). Inclusion criteria were: type 1 and 2 diabetic subjects with walking ability, no history of ulcers or neurological disorders (apart from neuropathy), orthopedic problems, lower limb surgery, cardiovascular disease. CS were recruited among hospital personnel and chosen to be age-, BMI- and gender-matched with the diabetic subjects. On the basis of these criteria 60 patients were examined: 20 CS, 40 diabetic patients (20 without peripheral neuropathy (NoDPN) and 20 DPN). All subjects gave written informed consent. The protocol was approved by the local Ethics Committee. Height and weight were recorded and body mass index (kg/m^2) was calculated.

The neurological evaluation included the assessment of symptoms, and signs compatible with peripheral nerve dysfunction. The Michigan Neuropathy Screening Instrument questionnaire was used [17]. Subjects were classified as neuropathic if they were found to be positive for three or more out of a total of 15 specified symptoms [18]. The physical examination consisted of: patellar and ankle reflexes, assessment of lower limb muscle strength, sensory testing (pin-prick), touch (10 g Semmens Weinstein monofilament) and vibration perception threshold (128 MHz tuning fork and Biothesiometer), pain sensitivity, electroneurophysiological study, and ankle-to-brachial systolic pressure ratio (Index of Winsor). Cardiovascular autonomic tests were also performed.

HbA1c values from the preceding ten years were collected. Each patient had at least one ophthalmologic examination, a urinary albumin-to-creatinine ratio measured, a carotid artery Doppler ultrasound examination, and a 12-leads electrocardiogram in the three months period preceding the study.

All subjects underwent clinical examination of the foot by a single orthopedic surgeon experienced in foot and ankle [14,19], in order to ensure reliability of the classifications and be consistent with clinical practice [18].

The type of foot (cavus, planus, normal), foot deformities (hallux valgus/normal/rigidus, claw and hammer toes, limitation of dorsiflexion of the great toe, abducted/adducted/overlapping toes), pre-ulceration lesions (calluses, soft corns) and hip, knee, and ankle joint mobility were assessed. Heel position and plantar foot arch during bipedal loading were also evaluated through both footprints [20] and static acquisitions [7] on the PP system. A foot was classified as: cavus if the middle third of the footprint covered less than the 2/3rd of the forefoot print's width; as planus if the width of the middle third of the footprint exceeded 1/3rd of the full foot width [20]. The heel deviation was evaluated by comparing the Helbing line (drawn along the Achilles tendon) with the vertical one. A valgus deviation higher than 3° was considered as valgus heel. Any deviation toward the varus was considered varus heel [20]. Hallux valgus was defined as a deviation of the great toe toward the lateral side of the foot with a prominence developed over the medial side of the first metatarsal head [13].

2.2. Experimental set up

Movement analysis was carried out using a 60 Hz six cameras stereophotogrammetric system (BTS S.r.l, Padova), two force plates (FP4060-10, Bertec Corporation, USA), two PP systems (410 mm × 410 mm × 0.5 mm, 0.64 cm^2 resolution, 150 Hz, Imagortesi, Piacenza). The signals coming from all systems were synchronized in post processing as in [21]. A four-segment 3D foot kinematic model was adopted. This was previously validated in our laboratory [5,21] and it allows the 3D evaluation of ankle, hindfoot, midfoot and forefoot kinematics [21,22]. A three-segment model for the plantar sub-area definition was obtained by means of projecting the anatomical landmarks of the kinematics protocol onto the footprint [21,23]. Thus, for each patient's foot the hindfoot, midfoot, forefoot subareas were defined as in [21].

The elaboration of PP distribution concentrated on the analysis of some meaningful parameters as in [21]: the center of pressure (COP) mediolateral (ML) and anteroposterior (AP) excursions and the curve integral [6], peak and mean pressure curves (PPC and MPC), and loaded surface curve (LSC).

The motion analysis protocol was organized with a static acquisition (subject in an upright posture, with feet placed with ankles together, toes pointed 30° apart and the arms along the body [5,6,21]) and gait analysis sessions.