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Gait parameters of people with diabetes-related neuropathic plantar foot ulcers

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ABSTRACT

Background: Foot ulceration associated with diabetic peripheral neuropathy is a global concern. Biomechanical investigation allows the identification of gait abnormalities that may adversely affect ulcer healing. The objective of this case–control study was to compare the gait parameters of cases with diabetes-related foot ulcers to controls.

Methods: Three-dimensional movement analyses were performed on 21 people with diabetes-related neuropathic plantar foot ulcers (cases), 69 people with diabetes without a foot ulcer history (diabetes controls) and 56 healthy controls. Outcome data were reported as mean differences, 95% confidence intervals and Cohen's d effect sizes. Binary logistic regressions were used to adjust for age, sex and body mass index.

Findings: People with foot ulcers had a smaller plantar flexion (Cohen's d = −0.6 vs. diabetes controls and d = −0.8 vs. healthy controls), knee flexion (d = −0.6 vs. diabetes controls and d = −1.0 vs. healthy controls) and pelvic obliquity (d = −0.9 vs. diabetes controls and d = −0.7 vs. healthy controls) (all $P < 0.05$). They also had a significantly greater range of anterior–posterior ground reaction force (d = 1.0 vs. diabetes controls and d = 1.7 vs. healthy controls) and total vertical ground reaction force (d = 0.9 vs. diabetes controls and d = 1.1 vs. healthy controls) and significantly slower walking speed and smaller step length compared to controls (all $P < 0.05$).

Interpretation: People with plantar foot ulcers have considerably different gait parameters to controls. Whether the observed gait parameters contributed to the ulcer development or are a response to the ulcer is currently unclear and needs further investigation.

1. Introduction

Diabetes-related foot ulcers (DFUs) are a leading cause of morbidity and mortality in people with type 2 diabetes (Boulton, 2004a; Singh et al., 2005; Lazzarini et al., 2012). Recent pooled estimates indicate that 2.4% of all hospitalised in-patients worldwide suffer from DFUs at any one time (Lazzarini et al., 2015). People with DFUs have significantly lower physical, mental and social health status compared to people without DFUs (Ribu et al., 2008). The most significant contributing factor in the development of DFUs is diabetic peripheral neuropathy (DPN) (Boulton et al., 2004). DPN has sensory, motor and autonomic components (Boulton et al., 2004). Sensory DPN has been strongly implicated in DFU formation due to loss of protective sensation (Armstrong, 2005; Wood et al., 2005). Motor DPN also appears important in the development of DFUs via altered gait parameters (Mueller et al., 1994a; Veves et al., 1992). In a systematic review, we previously demonstrated that people with DPN have different gait parameters than controls including different kinematics (such as increased hip flexion and knee extension), kinetics (such as reduced braking and propelling force) and

Abbreviations: DFU, Diabetes related foot ulcer; DPN, Diabetic peripheral neuropathy; PAD, Peripheral arterial disease; ABPI, Ankle brachial pressure index; PTI, Pressure time integral; ROM, Range of motion; UTWCS, University of Texas Wound Classification System.

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Table 1
Clinical and demographical characteristics of the study cohort.

Variable	DFU (n = 21)	DMC (n = 69)	HC (n = 56)	*P*-value
Age (years)	63.1 (10.6)	63.4 (9.6)[b]	57.6 (10.3)	0.004
Males	15 (71.4%)[b]	46 (66.7%)[b]	24 (42.9%)	0.011
Ethnicity				0.660
Caucasian	20 (%95.2)	65 (94.2%)	54 (98%)	
Australian Aboriginal/Indigenous/Torres-strait Islander	1 (4.8%)	2 (2.9%)	2 (3.6%)	
Other	–	2 (2.9%)	–	
Diabetes duration [years][#]	16.6 (7.1)	10.7 (8.6)	–	0.005
HbA1c (mmol/l)[#]	58.9 (16.8)	54.8 (13.3)	–	0.284
Uses Insulin[#]	13 (61.9%)	19 (27.5%)	–	<0.001
Smoking Status				0.201
Never Smoked	14 (66.7%)	34 (49.3%)	26 (46.4%)	
Ex-Smoker	6 (28.6%)	29 (42.0%)	29 (51.8%)	
Current Smoker	1 (4.8%)	6 (8.7%)	1 (1.8%)	
History of hypertension	19 (90.5%)[ab]	46 (66.7%)[b]	13 (23.2%)	<0.001
History of dyslipidaemia	14 (66.7%)[b]	45 (65.2%)[b]	14 (25.0%)	<0.001
History of stroke*	2 (9.5%)[b]	2 (2.9%)	0 (0.0%)	0.074
History of coronary heart disease	7 (33.3%)[ab]	18 (26.1%)[b]	2 (3.6%)	0.001
History of chronic heart failure	3 (14.3%)	9 (13.0%)	2 (3.6%)	0.148
History of chronic pulmonary disease	4 (19.0%)	14 (20.3%)[b]	4 (7.1%)	0.107
History of chronic liver disease	2 (9.5%)	5 (7.2%)[b]	0 (0.0%)	0.093
History of chronic renal impairment	5 (23.8%)[ab]	10 (14.5%)[b]	0 (0.0%)	0.003
Height [cm]	173.7 (9.8)	169.6 (10.6)	168.9 (9.7)	0.177
Weight [kg]	102.5 (23.8) [ab]	91.3 (15.2)[b]	74.4 (15.2)	<0.001
BMI [Body Mass Index]	34.0 (8.3)[b]	31.8 (4.80)[b]	26.1 (4.5)	<0.001
Body Fat Percentage [% bf]	28.5 (13.7)	27.8 (12.6)	28.2 (13.5)	0.974
Waist Circumference [cm]	113.5 (17.9)[b]	106.6 (11.2)[b]	86.2 (13.2)	<0.001
Hip Circumference[cm]	110.7 (18.9)[b]	105.8 (10.2)[b]	93.0 (44.7)	0.019
Left leg length [cm]	91.8 (7.1)	90.5 (5.6)	90.9 (4.8)	0.649
Right leg length [cm]	92.9 (8.0)	89.9 (11.4)	91.7 (4.9)	0.323
ABPI^	1.1 (0.2)	1.1 (0.2)	1.2 (0.1)	0.839
Monofilament score	7 (7) [ab]	18 (4)	20 (0)	<0.001
MNSI symptom score[#]	7 (1)	5 (2)	–	<0.001
MNSI physical assessment score[#]	7 (1)	2 (2)	–	<0.001

Legend: All data represents mean (standard deviation) or number and percentages (%). DFU = diabetic foot ulcer group, DMC = diabetes mellitus control group HC = healthy control group. The reported *P*-values indicate main comparison outcomes from one-way ANOVA, Pearson's Chi squared tests or Fishers exact tests between three groups unless indicated by # = DFU vs. DMC comparison only. [a] = $P < 0.05$ vs. DMC group, [b] = $P < 0.05$ vs. HC group on post-hoc tests. A significance level of $P < 0.05$ was used throughout. Diabetes duration indicates fractions of years living with type 2 diabetes mellitus. ^ABPI values represented in the table are for ulcerated limbs of the DFU groups and the lowest reported in the control groups. Monofilament score is out of a total of 20, measured at ten sites for each foot. MNSI scores indicate the total scores from the Michigan Neuropathy Screening Instrument in relation to the neuropathy symptom score and physical assessment score. * Note that the four patients with stroke did not have a history of gait disturbance due to their stroke as the stroke only affected their speech function.

spatio-temporal parameters (STP) (such as a longer stance time) (Fernando et al., 2013). The differences in gait parameters are thought to result from DPN which causes restricted lower limb joint range of motion (ROM) and foot-joint deformities which in turn contribute to elevated plantar pressures (Dinh and Veves, 2005; Fernando et al., 1991; Frykberg et al., 1998). Elevated plantar pressures during gait in the presence of sensory DPN increases plantar tissue trauma and predisposes people to DFUs (Boulton, 2004b; Masson et al., 1989; Wrobel and Najafi, 2010).

Most research in the field has focused on assessing plantar pressures before the development, or after the healing, of DFUs (Fernando et al., 2013; Akashi et al., 2008; Sacco et al., 2010; Savelberg et al., 2009; Raspovic, 2013). This research has suggested that reducing plantar pressures prevents DFUs from occurring and allows optimal healing if they develop (Wrobel and Najafi, 2010; Cavanagh and Bus, 2011). Hence current international guidelines advocate reducing maximum plantar pressure to prevent foot ulcers (Bus et al., 2016). Although there is information regarding how gait parameters may predispose to ulcer development, there are very few studies that have investigated gait parameters during active ulceration. Hence the gait parameters (kinematics, kinetics and STPs) of patients with active plantar ulceration remain poorly understood (Fernando et al., 2013). It is important to understand gait parameters during active ulceration as these may differ from those before ulcer development or after ulcer healing (Raspovic, 2013; Fernando et al., 2014). A comprehensive biomechanical investigation of participants with active DFUs may allow identification of abnormal gait parameters that adversely affect ulcer healing (Formosa et al., 2013). This knowledge may allow for a more precise formulation of tailored treatments that include existing recommendations to reduce plantar pressure in conjunction with novel interventions to promote gait changes (Davis, 1997).

The aim of this case–control study was to comprehensively assess the kinematic, kinetic and STPs in cases with active DFUs using three-dimensional movement analyses. We had three overall hypotheses, that compared to diabetes and healthy controls, people with plantar neuropathic DFUs would display:

1. Significantly restricted angular kinematic variables in the lower limb;
2. Significantly increased kinetic parameters, leading to a higher planar load distribution;
3. Significantly restricted STPs.

2. Methods

2.1. Study design and setting

This was a case–control study nested in a six-month longitudinal research project, conducted in a single regional Australian site. A full study protocol has been previously published (Fernando et al., 2015). In brief, there were three groups of eligible participants: People with type 2 diabetes with an active plantar neuropathic foot ulcer (cases; DFU group); people with type 2 diabetes without a history of foot ulceration