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Plantar pressure and daily cumulative stress in persons affected by leprosy with current, previous and no previous foot ulceration

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ABSTRACT

Not only plantar pressure but also weight-bearing activity affects accumulated mechanical stress to the foot and may be related to foot ulceration. To date, activity has not been accounted for in leprosy. The purpose was to compare barefoot pressure, in-shoe pressure and daily cumulative stress between persons affected by leprosy with and without previous or current foot ulceration.

Nine persons with current plantar ulceration were compared to 15 with previous and 15 without previous ulceration. Barefoot peak pressure (EMED-X), in-shoe peak pressure (Pedar-X) and daily cumulative stress (in-shoe forefoot pressure time integral × mean daily strides (Stepwatch™ Activity Monitor)) were measured.

Barefoot peak pressure was increased in persons with current and previous compared to no previous foot ulceration (mean ± SD = 888 ± 222 and 763 ± 335 vs 465 ± 262 kPa, $p < 0.05$). In-shoe peak pressure was only increased in persons with current compared to without previous ulceration (mean ± SD = 412 ± 145 vs 269 ± 70 kPa, $p < 0.05$). Daily cumulative stress was not different between groups, although persons with current and previous foot ulceration were less active.

Although barefoot peak pressure was increased in people with current and previous plantar ulceration, it did not discriminate between these groups. While in-shoe peak pressure was increased in persons with current ulceration, they were less active, resulting in no difference in daily cumulative stress. Increased in-shoe peak pressure suggests insufficient pressure reducing footwear in persons with current ulceration, highlighting the importance of pressure reducing qualities of footwear.

1. Introduction

Increased plantar pressure is thought to be one of the risk factors of foot ulceration in people affected by leprosy [1,2]. Many persons affected by leprosy, although treated, still have or develop foot impairments and are therefore at risk of foot ulceration [3,4]. Foot ulceration is a major health and social problem, which may subsequently lead to amputation and cause disability in people with leprosy [5].

Foot problems in leprosy are often compared to the diabetic foot [6], although the pathologies associated with diabetes and leprosy are intrinsically different and will influence issues such as the body's response to mechanical stress. In diabetes, besides nerve impairments also complications such as cardiovascular insufficiency and tissue glycosylation affect the foot.

Most neuropathic ulcers in leprosy develop on the plantar aspects of the feet, with around 70% occurring on the forefoot [7]. Recurrence of foot ulceration is high [8], although some believe foot ulcers can be prevented through the use of appropriate footwear and preventive foot care [9,10].

Research into the role of plantar pressure and the effect of footwear in neuropathic foot ulcers of persons affected by leprosy has often been observational or linked to studies in the diabetic foot and is therefore limited. Barefoot peak plantar pressure was shown to be higher in persons affected with leprosy compared to healthy controls [11], and increased in persons with chronic active foot ulceration [12]. The assessment of barefoot peak plantar pressure has been proven to be useful as it shows the direct consequence of foot deformities and/or altered foot shape on pressure distribution and is predictive of (diabetic) neuropathic foot ulceration [13,14]. Persons with foot deformities are generally provided with special footwear to decrease the risk of developing foot ulceration. In-shoe pressure measurement can be used to establish the pressure reducing qualities of this footwear and has been used in preliminary studies in leprosy [15,16]. However, not only the amount of pressure but also activity level influences the

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amount of accumulated mechanical trauma to the foot [17]. For example, a highly active person with foot deformities who is using footwear with limited cushioning is expected to have a higher level of cumulative stress compared to someone with a low level of activity or using effective pressure reducing footwear. Because it was previously shown that persons affected by leprosy with foot impairments have reduced daily walking activity [18], this may subsequently affect daily cumulative stress. A lower daily cumulative stress was previously shown in patients with a history of diabetic foot ulceration compared to (non-) diabetic controls [19], nevertheless the importance of physical activity is not yet well understood and has not been studied before in persons with leprosy.

The purpose of this study was to compare barefoot peak pressure of the foot, in-shoe peak pressure of the foot and daily cumulative stress between persons affected with leprosy with a current, a previous and without a previous plantar foot ulcer and to explore which parameter was most strongly related to current foot ulceration.

2. Methods

2.1. Design and sample

A cross-sectional study was performed in people affected by leprosy (previously treated) from the outpatient clinic of the department of Dermatology at the Academic Medical Center in Amsterdam, The Netherlands. Inclusion criteria were: leprosy diagnosed according to the Ridley and Jopling classification (1966) and a minimum age of 18 yrs. Persons who agreed to participate were assigned to the following groups: (1) persons with no previous foot ulcer (NU); (2) persons with a self-reported previous plantar foot ulcer (PU); (3) persons with a current plantar foot ulcer (CU).

The study was approved by the Local Ethics Committee and informed consent was obtained prior to the start of the study. Data were recorded as part of a larger, cross-sectional study on the consequences of leprosy impairments [18,20,21].

2.2. Clinical foot examination

A detailed foot examination was performed and included assessment of: quantitative sensory testing (vibration perception threshold (VPT), pressure perception threshold (PPT) and Neurological Disability Score (NDS)), presence of foot deformities, presence of callus, mobility of ankle and first metatarsophalangeal (MTP 1) joint and muscle strength of the ankle dorsal and plantar flexors. Details of the assessment have previously been described [18].

2.3. Foot pressure measurements

Barefoot plantar pressure was assessed while walking over the EMED-X pressure platform (Novel GmbH, Munich, Germany) built in a walkway, which has a spatial resolution of 4 sensor/cm^2 and a sampling frequency of 100 Hz. A 2-step protocol was used [22]. In participants with current foot ulceration, a thin transparent dressing (Tegaderm^{TM}) was placed over the ulcer site, so that foot pressure could be measured. Trials in which the investigator noticed a deviation from the participants' normal walking pattern (i.e. targeting) were not used for analysis. Data of four footsteps was used for analysis.

In-shoe plantar pressure was measured while walking at a self selected pace over a 10 m walkway using the Novel PEDAR-X system (Novel GmbH, Munich, Germany). This system comprises a 2.2 mm thick flexible pressure-sensing insole with 99 sensors, the spatial sensor resolution is therefore dependent of the insole size (average = 1 sensor/cm^2) and has a sampling rate of 50 Hz. Participants were assessed in their own footwear. Several practice trials were performed to ensure natural cadence and trials in which the investigator noticed a deviation from the patient's normal walking pattern were not used for analysis. Data of four walking trials were used for analysis.

2.4. Walking activity

To calculate daily accumulative stress the mean daily strides were counted using the StepWatch^{TM} Activity Monitor (SAM) (Orthocare Innovations, Mountlake Terrace, WA, USA). The SAM was worn on the right ankle for seven consecutive days, except when sleeping, bathing, showering or swimming. A diary was kept to register daily activities (such as walking, sleeping and cycling). Activity data was corrected for cycling activity, by deleting any activity within a cycling period as indicated in the diary.

2.5. Data processing and analysis

All analysis was performed using data from the extremity with a previous or current plantar foot ulceration, and data from the right foot in cases of bilateral or no previous foot ulceration.

Novel-win software was used to analyse pressure data of both barefoot and in-shoe pressure.

For barefoot pressure, peak pressure of the whole foot was calculated. For in-shoe pressure only mid-gait footsteps were selected for analysis. Automated masking was used to create a mask of the forefoot (defined as the distal half of the total foot length) [19]. In-shoe peak pressure of the whole foot and pressure time integral of the forefoot was calculated. Peak pressure was defined as the maximum pressure recorded by any sensor during one footstep. The pressure time integral within a region was defined as the cumulative peak pressure during contact time of one footstep and reflects both the magnitude and duration of plantar loading throughout the stance phase of gait.

SAM daily stride counts were averaged over the seven-day monitoring period to determine mean daily strides for each participant. The mean daily stride count was

Table 1
Subject characteristics.

		NU	PU	CU	*p*
Number of persons		15	15	9	
Sex	Male/female	8/7	9/6	6/3	ns
Age (yrs)		49.2 ± 11.5	66 ± 14.8*	66.7 ± 9.6*	*<0.01 vs NU
Weight (kg)		70.2 ± 16.5	82.5 ± 27.0	81.7 ± 18.3	ns
Foot ulcer	Right/left	N/a	11/13	6/4	ns
	Unilateral/bilateral	N/a	12/6	8/1	ns
Orthopaedic footwear	Y/N	3/12	6/8 (1 missing)	6/3	=0.073
Nerve function	VPT (V)	8.6 ± 5.7	25.8 ± 11.9	18.1 ± 4.4	<0.001
	PPT (disturbed Y/N)	4/11	12/3	9/0	<0.01
	NDS (0–10)	1 (0/3)	3 (3/5)	5 (4.5/5)	<0.001
Foot deformities (Y/N)	Toe amputation or absorption	3/12	7/8	8/1	<0.001
	Claw or hammer toes*	6/9	6/6	4/1	ns
	Hallux valgus*	1/14	0/11	3/4	<0.05
	Charcot deformity	1/14	1/14	2/7	ns
Callus	Y/N	7/8	12/3	8/1	<0.05
Joint mobility (degrees)	Ankle DF	10 (9/12)	10 (7/13)	10.5 (0.5/14.7)	ns
	MTP1 extension	69 (62/90.5)	48 (41.2/59.5)	32 (25/54)	<0.001
Muscle strength (0–5)	Ankle DF	5 (5/5)	5 (4/5)	5 (4.5/5)	ns
	Ankle PF	5 (5/5)	5 (5/5)	5 (5/5)	ns

Data shown of right foot, unless (unilateral) ulcer on left foot. Data shown as frequency, mean ± SD, median (p25/p75). Significance testing using ANOVA post hoc for parametric data, Kruskal Wallis analysis for non-parameteric data and chi-squared testing for nominal data. NU, without previous foot ulceration; PU, previous foot ulceration; CU, current foot ulceration; VPT, vibration perception threshold; PPT, pressure perception threshold; NDS, neuropathy disability score; DF, dorsal flexion; MTP1, first metatarsalphalangeal; PF, plantar flexion.

* Toe deformities (claw/hammer toes and hallux valgus) were not scored when significant toe absorption present at same time.