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Plantar pressures are higher under callused regions of the foot in older people

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Summary

Background. Mechanically induced hyperkeratotic lesions (corns and calluses) are among the most common foot problems in older people. However, their aetiology is not well understood.

Aim. To compare the magnitude of pressures generated under the foot when walking in older people with and without plantar calluses.

Methods. Peak plantar pressure measurements were obtained from 292 participants (99 men and 193 women) aged 62–96 years (mean ± SD 77.6 ± 6.9) recruited from a retirement village and a university health sciences clinic. Comparisons were then made between callused and noncallused regions of the foot.

Results. In total, 151 participants (52%) had at least one plantar callus. Those with plantar calluses were more likely to be female, have moderate to severe hallux valgus, and at least one lesser toe deformity. Regional peak plantar pressures were significantly higher in people with calluses under the second metatarsophalangeal joint (2.34 ± 0.46 vs. 2.12 ± 0.51 kg/cm^2, $P = 0.001$), the third to fifth metatarsophalangeal joints (1.71 ± 0.46 vs. 1.50 ± 0.51 kg/cm^2, $P = 0.009$) and the hallux (1.40 ± 0.34 vs. 1.23 ± 0.47 kg/cm^2, $P = 0.007$) compared with people without calluses under these sites.

Conclusion. Plantar pressures are significantly higher under callused regions of the foot in older people. Raised pressure may play a role in the development of plantar calluses by accelerating the turnover rate of keratinocytes in the epidermis. Future studies should focus on evaluating the efficacy of pressure-relieving interventions in the prevention and treatment of keratotic disorders in older people.

Introduction

Hyperkeratotic lesions (corns and calluses) are one of the most prevalent foot problems in older people, affecting 20–65% of people aged > 65 years of age.[1–3] Although often considered a relatively minor problem, keratotic lesions can cause considerable pain and disability. It has been demonstrated that older people with plantar keratotic lesions have greater difficulty walking on level ground and in ascending and descending stairs, and show worse performance in tests of balance ability.[4] Furthermore, if left untreated, keratotic lesions may cause damage to deeper tissues and lead to ulceration, particularly in people with diabetes mellitus.[5]

The physiological mechanism responsible for the development of hyperkeratotic lesions is not fully understood. In response to repetitive friction or pressure, normal healthy skin undergoes accelerated keratinization and a lower rate of desquamation, resulting in an increase in the thickness of the stratum corneum.[6] This

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process, sometimes referred to as physiological hyperkeratosis, is considered to be a protective mechanism that prevents damage to deeper tissues by dispersing the applied forces over a larger area and volume of skin.[7] Histological studies have revealed several notable changes in callused skin, including an increase in the thickness of the stratum corneum and stratum granulosum, a decrease in density (but an increase in thickness) of keratinocytes and an exaggerated pattern of rete pegs.[7] These changes are thought to represent an increased rate of epidermal cellular production and an associated decrease in the differentiation of keratinocytes. Corns have a similar structure; however, the underlying dermis exhibits significant degeneration of collagen fibres and an increased number of fibroblasts.[8]

For reasons that are still largely unknown, in some individuals the process of hyperkeratosis becomes excessive, resulting in a large build-up of dense keratinized tissue. Although raised pressures under the foot when walking have been shown to be associated with development of calluses in people with diabetes,[9] only one investigation has provided evidence that plantar calluses develop in regions of raised pressure in otherwise healthy older people.[10] However, the control participants in this study were not well matched for age, and no consideration was given to other factors that may influence plantar pressure, such as walking speed,[11] bodyweight[12] and foot deformity.[13] Furthermore, because pressure data from different sites were pooled prior to analysis, it is not possible to determine from that study whether the relationship between pressure and calluses differs according to the region of the foot that is affected.

In response to these limitations, the present study was undertaken to determine whether participant characteristics (such as age, gender and foot deformity) are associated with the presence of plantar calluses, and whether peak plantar pressures when walking are raised under specific sites of the foot in people with calluses under those sites.

Methods

The Human Studies Ethics Committee at La Trobe University approved the study, and informed consent was obtained from all participants.

Participants

The study population comprised 292 participants (99 men and 193 women) aged 62–96 years (mean ± SD 77.6 ± 6.9) recruited from a retirement village ($n = 174$) and a university health sciences clinic ($n = 118$) as part of a study on foot risk factors for falls. Structural correlates of plantar pressures in the retirement village cohort have been reported previously.[12] People were deemed ineligible for the study if they had Parkinson's disease, were unable to ambulate household distances without an assistive device, or scored < 7 on the Short Portable Mental Status Questionnaire.[14]

Medical history questionnaire and demographic information

Participants completed a medical history questionnaire pertaining to the prevalence of major medical conditions, medication use, mobility and activities of daily living. Height was measured in metres and weight in kilograms, and body mass index (BMI) was calculated as kg/m^2.

Foot assessment

Foot deformity was evaluated by documenting the presence of hallux valgus, lesser toe deformities, corns and calluses. The presence and severity of hallux valgus was determined using the Manchester scale.[15] This instrument consists of standardized photographs of feet with four levels of hallux valgus. The grading of hallux valgus using this tool is highly correlated with hallux valgus measurements obtained from foot radiographs.[16] Presence of lesser digital deformity and plantar calluses was documented on a foot map.[4] No distinction was made between calluses and corns. The reliability of these observations has been previously established.[17]

Assessment of walking speed

Because previous studies indicate that differences in walking speed may confound plantar pressure measurements,[11] walking speed was determined with a stopwatch by measuring the time taken (in seconds) to walk 10 m, and was expressed as m/s.

Plantar pressure measurement

Plantar pressures were recorded during level barefoot walking using a system (MatScan®; Tekscan, Boston, MA) comprising a 5-mm thick floor mat (432 mm × 368 mm) incorporating 2288 resistive sensors (1.4 sensors/cm^2) sampling at a rate of 40 Hz. The two-step gait initiation protocol[18] was used to obtain foot pressure data, as it requires fewer trials than the midgait protocol and has similar retest reliability. Three

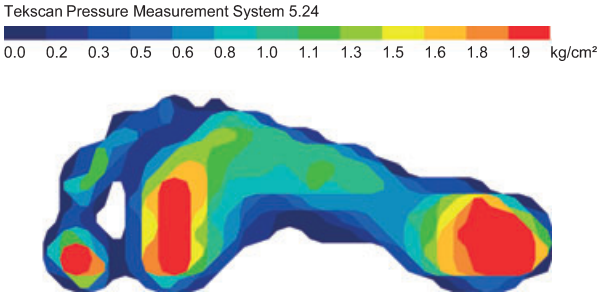

Figure 1 Typical output of the plantar pressure measurement system.

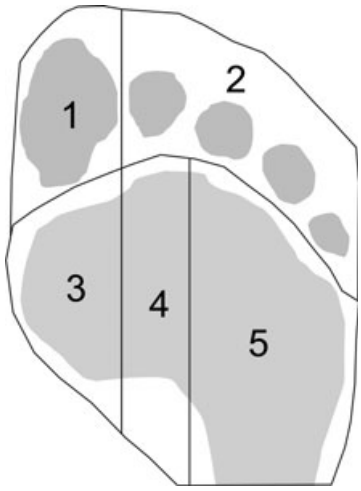

Figure 2 The mask used to define the five regions of the forefoot for plantar pressure analysis: 1, hallux; 2, lesser toes; 3, first metatarsophalangeal joint; 4, second metatarsophalangeal joint; 5, third to fifth metatarsophalangeal joints.

trials were recorded, which has been found to be sufficient to ensure adequate reliability of pressure data.[19] Following data collection, Research Foot software (version 5.24) was used to construct individual 'masks' to determine peak pressures under five regions of the foot: the hallux, the lesser toes, the first metatarsophalangeal joint, the second metatarsophalangeal joint, and the third to fifth metatarsophalangeal joints (Figs 1 and 2).

Statistical analysis

Only data from the right foot were analysed. Lesion site was considered the unit of analysis, and comparisons were made between callused and noncallused sites irrespective of the presence of other lesions on the same foot. Variables with right-skewed distributions were log transformed. Comparisons between participants with and without calluses were undertaken using χ^2 and odds ratios (for dichotomous variables) and independent samples *t*-test (for continuous variables). Logistic regression was then undertaken to determine which factors were most strongly associated with the presence of plantar calluses. The magnitude of observed differences in peak plantar pressures between participants with and without calluses was determined by calculating effect sizes (Cohen's *d*). Effect sizes were categorized as negligible ($d < 0.15$), small ($d = 0.15$–0.40), medium ($d = 0.41$–0.75) or large ($d > 0.75$).[20] All data were analysed using SPSS for Windows software (SPSS Inc., Chicago, IL, USA).

Results

Prevalence and patterns of plantar calluses

Just over half (52%) of the sample had at least one plantar callus. Of these participants, the most common region of the foot affected was the first metatarsophalangeal joint (53%), followed by the second metatarsophalangeal joint (44%) and the hallux (43%). Characteristics of participants with and without plantar calluses are shown in Table 1. Participants with at least one plantar callus were more likely to be female ($\chi^2 = 9.10$, d.f. = 1, $P = 0.003$), have moderate to severe hallux valgus ($\chi^2 = 34.67$, d.f. = 1, $P < 0.001$), have at least one toe deformity ($\chi^2 = 10.83$, d.f. = 1, $P = 0.001$) and report foot pain ($\chi^2 = 6.78$, d.f. = 1, $P = 0.012$). Walking speed did not differ between the groups ($t_{290} = -1.32$, $P = 0.188$).

When each of these factors were entered into a logistic regression, moderate to severe hallux valgus (OR = 4.79, 95% CI 2.59–8.86, $P < 0.001$) and having at least one lesser toe deformity (OR = 1.97, 95% CI 1.14–3.40, $P = 0.016$) remained significantly associated with the presence of plantar calluses.

Plantar pressures in people with and without plantar calluses

Peak plantar pressures under sites with and without plantar calluses are shown in Table 2. Sites with callus demonstrated significantly higher peak plantar pressures under the hallux ($t_{290} = -2.74$, $P = 0.007$), second metatarsophalangeal joint ($t_{290} = -3.12$, $P = 0.001$) and third to fifth metatarsophalangeal joints ($t_{290} = \chi^2$ 2.70, $P = 0.009$), with mean increases of 9–12%. The effects sizes were small to medium. However, there were no significant differences in peak pressure in

Table 1 Characteristics of participants with and without plantar calluses.

Condition	No calluses ($n = 141$)	Calluses ($n = 151$)	All ($n = 292$)
Age, years (SD)	78.1 (7.0)	77.1 (6.7)	77.6 (6.9)
Women, *n* (%)**	86 (57)	112 (74)	193 (66)
Height, m (SD)	1.63 (0.09)	1.60 (0.07)	1.62 (0.09)
Weight, kg (SD)	72.4 (14.3)	71.2 (13.6)	71.8 (13.9)
Body mass index, kg/m^2	27.1 (4.5)	27.7 (4.4)	27.4 (4.4)
Obese (BMI > 30), %	46	54	52
Medical conditions, %			
Heart condition	31	21	26
Stroke	3	7	5
Diabetes	12	17	14
Peripheral vascular disease	17	17	17
Foot problems, %			
Moderate to severe hallux valgus**	12	43	28
At least one lesser toe deformity**	59	77	68
Foot pain**	25	39	32
Walking speed, per ms (SD)	0.89 (0.22)	0.85 (0.21)	0.87 (0.21)

*Significant difference between groups at *p<0.05 level, **p<0.01.

Table 2 Peak plantar pressures (kg/cm^2) at sites with and without plantar calluses.

Site	*n* (%)*	No callus	Callus	% mean difference	Effect size	*P*-value
Hallux	65 (22)	1.23 (0.47)	1.40 (0.34)	+ 12.3	0.38 (small)	0.007
Lesser toes	22 (8)	0.75 (0.29)	0.77 (0.30)	+ 2.9	0.07 (negligible)	0.734
First MPJ	81 (28)	1.65 (0.47)	1.74 (0.56)	+ 4.8	0.18 (small)	0.235
Second MPJ	67 (23)	2.12 (0.51)	2.34 (0.46)	+ 9.2	0.44 (medium)	0.001
Third to fifth MPJs	46 (16)	1.50 (0.51)	1.71 (0.46)	+ 11.9	0.42 (medium)	0.009

*Number of participants (%) with calluses under this region of the foot. MPJ, metatarsophalangeal joint.

callused and non-callused sites under the first metatarsophalangeal joint ($t_{290} = -1.29$, $P = 0.235$) or the lesser toes ($t_{290} = -0.35$, $P = 0.734$).

Discussion

The first objective of this study was to determine whether participant characteristics were associated with the presence of plantar calluses. The findings indicate that older people with at least one plantar callus are more likely to be female, have moderate to severe hallux valgus and at least one toe deformity. The gender difference in callus prevalence is consistent with several previous reports.[2,3] The underlying mechanism for the significantly higher prevalence of plantar calluses in women is likely to be related to the higher prevalence of toe deformities and the contribution of footwear with an elevated heel and narrow toebox. It has recently been shown that women are more likely than men to wear ill-fitting footwear, and that heel elevation is significantly associated with the presence of plantar calluses.[21] The association between plantar calluses and hallux valgus is also consistent with previous studies,[4] and suggests that the impaired propulsive function of the hallux associated with the condition leads to increased loads being applied to the metatarsal heads.[22]

The second objective was to determine whether peak plantar pressures when walking are raised at specific sites of the foot in people with calluses under those sites. The results indicated that peak plantar pressures were significantly raised for all forefoot regions in participants with calluses, with the exception of the first metatarsophalangeal joint and the lesser toes. The observation of raised peak pressures under callused regions is consistent with the findings of Potter and Potter.[10] However, the magnitude of the observed increase in the current study (9–12%) is considerably less than the 25% increase reported by Potter and Potter.[10] The most likely explanation for this discrepancy is that the callused group in the Potter and Potter[10] study were considerably older than the non-callused control group (mean age of 67 years vs. 48 years). Because age is associated with an increased prevalence of foot deformities known to alter pressure patterns (such as hallux

valgus and lesser toe deformities),[13] it is likely that some degree of the observed 25% increase was due to these factors rather than the presence of calluses.

Although significant increases in peak pressure were noted under the second metatarsophalangeal joint, third to fifth metatarsophalangeal joints and the hallux in people with calluses, no significant differences were observed for the first metatarsophalangeal joint or the lesser toes. There are several likely explanations for these null results. For the first metatarsophalangeal joint, no distinction was made between centrally located calluses and lesions located on the plantar–medial aspect of the joint (sometimes referred to as 'roll-off' calluses). The pathomechanical process responsible for the development of calluses on the plantar–medial aspect of the joint is likely to be quite different to those located directly under the joint. Such lesions may develop in response to pressure from footwear or tangential (shear) forces during propulsion, rather than increases in vertical peak pressures. The lack of a significant difference between callused and non-callused lesser toes may be due to inadequate sample size (only 22 participants exhibited calluses in this region). It is also possible that barefoot testing underestimates the magnitude of pressures borne by the toes when shod, as it is likely that the elongation of the toes during propulsion is partly constrained by footwear.

The cross-sectional study design used in this study limits the degree to which the association between raised pressure and calluses can be considered causal. Rather than increased pressure leading to the development of calluses, it is possible that calluses form for other reasons, and their presence subsequently leads to increases in plantar pressure. Indeed, in people with diabetes, it has been shown that removal of calluses with a scalpel leads to significant reductions in plantar pressure.[9,23,24] However, following callus debridement, pressures under the metatarsophalangeal joints are still raised compared with people without calluses.[25] These findings suggest that the relationship between raised pressure and calluses may involve a positive feedback mechanism. That is, calluses may initially form under sites of raised pressure, but once they have formed, they may act as a foreign body and contribute to further increases in pressure. The relationship between raised pressures and calluses is also physiologically plausible, as histological studies of callused skin have revealed structural changes similar to those observed in experimental studies in which frictional loads are applied to the skin of laboratory animals.[7]

The findings of this study have important implications for clinical practice. Given that calluses appear to form under regions of raised plantar pressure, various off-loading techniques may play a significant role in both the prevention and treatment of these lesions. Several studies in patients with diabetes have shown that high plantar pressures can be alleviated with footwear and orthotic interventions,[26–29] and one study has shown that orthoses can reduce the thickness of plantar calluses.[30] Few studies have been undertaken on older people, although there is some evidence that the use of shock-absorbing insoles in conjunction with scalpel debridement is more effective at reducing pain associated with calluses than is debridement alone.[31] The appropriate management of painful plantar calluses using such techniques has the potential to improve mobility and independence in older people, as it has previously been shown that calluses impair balance and functional ability.[4] Furthermore, early recognition and treatment of plantar calluses may prevent skin breakdown, as plantar calluses frequently precede foot ulceration.[5]

In conclusion, this study confirms that callused regions of the foot (with the exception of the first metatarsophalangeal joint and the lesser toes) exhibit significantly raised peak pressures during gait. This finding provides useful insights into the aetiology of this common and frequently disabling condition. Future studies should focus on evaluating the efficacy of various pressure-relieving interventions in the prevention and treatment of keratotic disorders in older people.

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