Gel-filled (Liqua Care®) therapeutic insoles reduce peak forefoot pressure and increase TcpO2 in individuals with diabetes mellitus and peripheral vascular insufficiency

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Gel-filled (Liqua Care®) therapeutic insoles reduce peak forefoot pressure and increase $TcpO_2$ in individuals with diabetes mellitus and peripheral vascular insufficiency

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Abstract

Objectives

Co-existing diabetes and peripheral vascular disease have increased susceptibility to plantar ulceration. Therapeutic insoles reduce plantar pressure, but the effect on transcutaneous tissue oxygenation ($TcpO_2$) is unknown. This study examines the effect of gel-filled Liqua Care® therapeutic insoles on plantar pressure, and foot $TcpO_2$, in at-risk individuals with diabetes and peripheral vascular insufficiency.

Research design and methods

Ankle brachial pressure index (ABPI) in both lower limbs was measured in patients attending the diabetes centre for complication screening; 21 individuals with ABPI <0.9 and no active ulceration were invited to participate in the study. $TcpO_2$ was measured at the apex of the great toes both before, and after a 2-week period of Liqua Care® insole use. Recordings of in-shoe pressure measurements without, and with the therapeutic insole were made to ascertain any regional redistribution of plantar pressures (forefoot, midfoot and hindfoot).

Results

A mean reduction in peak forefoot pressure of 54.7 kPa (95% confidence interval (CI) 31.7–77.8 kPa, p<0.01) was observed. Mean great toe $TcpO_2$ increased by 2.92 mmHg (95% CI 0.87–4.97 mmHg, p<0.01).

Conclusions

These insoles may prevent new and recurrent pedal ulceration in at-risk patients with diabetes and peripheral vascular disease.

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Key words: diabetes, diabetic foot, insoles, pedal ulcers

Abbreviations and acronyms

ABPI	ankle brachial pressure index
CI	confidence interval
BMI	body mass index
HbA_{1c}	glycated haemoglobin A_{1c}
NHS	National Health Service
$TcpO_2$	transcutaneous tissue oxygenation

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Introduction

Individuals with diabetes have a 15–25% lifetime risk of foot ulceration,[1] which can lead to considerable morbidity,[2] limb loss[3] and mortality.[4,5] Hospitalisation of a patient with diabetes is more likely to occur as a consequence of foot disease than any other complication,[6] and the resulting healthcare expenditure may represent up to 20% total diabetes expenditure in Europe and North America.[7,8] With estimates of diabetes incidence predicted to see the greatest increases in the developing world,[9] diabetic foot ulceration is recognised as a global issue of major economic importance.

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Table 1. Subject characteristics at enrolment

Patient ID#	Sex (male/female)	Age (years)	Weight (kg)	BMI (kg/m^2)	Sensation	ABPI	HbA_{1c} (%)	Diabetes duration (years)
2	M	62	84	28	impaired	0.44	5.8	17
3	F	75	64	25	impaired	0.6	6.3	9
5	F	75	85	36	normal	0.88	7.7	18
6	F	61	82	29	normal	0.78	6.1	40
7	M	69	85	28	impaired	0.86	6.7	3
8	M	66	80	31	normal	0.82	6.7	5
9	M	76	82	30	normal	0.54	6	17
10	F	68	67	29	normal	0.82	6.7	6
11	F	77	64	25	normal	0.6	8.1	29
12	F	74	51	20	impaired	0.52	7.4	15
13	F	40	80	33	normal	0.73	7.8	28
14	F	69	72	30	impaired	0.84	8.6	11
15	M	73	87	28	normal	0.8	8.3	6
16	M	60	72	27	normal	0.65	8.7	3
17	M	64	75	28	normal	0.79	7.9	10
18	M	77	74	28	normal	0.82	7.5	14
19	M	75	92	36	normal	0.74	7.1	33
20	M	67	103	30	impaired	0.71	8.5	18
21	M	53	105	32	impaired	0.73	9.7	24
22	M	71	108	34	normal	0.68	7	10
23	M	59	113	30	normal	0.88	8.4	2
n=21	M=13 F=8	67±9[#]	82±16[#]	29.4±3.7[#]		0.73±0.13[#]	7.5±1[#]	15±10[#]

[#] Data are mean ± standard deviation

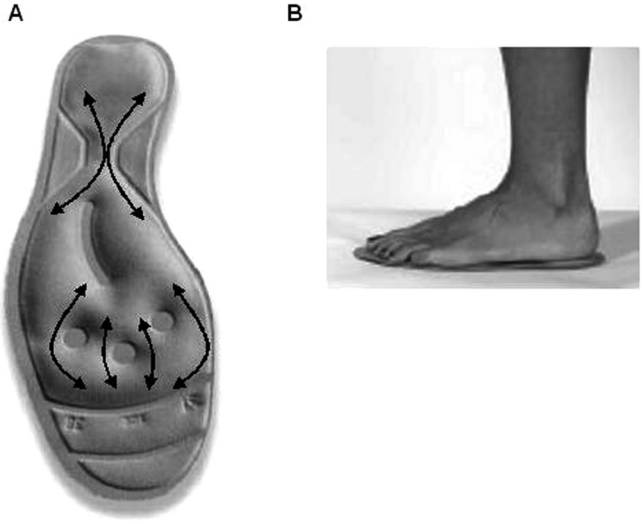
Key: ABPI = ankle brachial pressure index; BMI = body mass index; HbA_{1c} = glycated haemoglobin A_{1c}

Peripheral vascular disease is a common finding in individuals with diabetes,[10] and together with peripheral neuropathy they represent the major risk factors for development of pedal ulceration.[11] Reduced vascular supply to an affected foot significantly delays healing, and is often associated with poor outcome. The ABPI is a reliable non-invasive indicator of the presence of vascular insufficiency in diabetic limbs,[12] and is a routine investigation in the presence of foot ulceration. Transcutaneous measurements of tissue oxygenation have been shown to correlate with vascular disease severity in ischaemic foot ulcers which occur in patients with diabetes,[13] with successful wound healing associated with higher $TcpO_2$ values.[14]

Numerous strategies (targets for glycaemic control, blood pressure and lipids, smoking cessation, complication screening, specialist podiatry, patient education, and pressure relief) have been adopted with the aim of preventing foot ulcers in diabetes patients with neuropathy, vascular insufficiency or both.[15,16] Therapeutic insoles are a simple and cost effective way to prevent ulcers developing[17] and have been shown to be effective in reducing peak foot pressure.[18] In particular, insoles can be applied in most diabetes care settings with minimal training. The ability of a specific insole to enhance foot tissue oxygenation in patients at risk is an attractive treatment goal.

In this observational study we examined the effect of Liqua Care® insoles. These insoles contain a non-toxic precisely measured liquid which flows through a patented liquid control system with anatomically designed channels controlling the direction of the liquid. This ensures directional stability during walking or standing and matches the flow of liquid to the structure of the foot. The Liqua Care® insoles retail in the region of £27. We examined the effect of Liqua Care® on peak plantar pressure in 21 patients with either type 1 or type 2 diabetes and ABPI <0.9 using the F-Scan system.[19] In addition, we tested $TcpO_2$ in both feet before, and after study participants wore the insoles for 2 weeks, with the aim of demonstrating reduced peak pressures and an improvement in tissue oxygenation. There are no previously published studies investigating the use of Liqua Care® insoles.

Figure 1. Liqua Care® insole. Arrows indicate flow of gel between interconnecting compartments, which facilitates transfer of pressure between forefoot, midfoot and hindfoot. (B) The thin profile allows Liqua Care® insoles to be accommodated by existing footwear



Research design and methods

Study participants

We enrolled 21 patients all with type 2 diabetes (13 men and 8 women, aged 67 ± 9 (mean ± SD) years with weight 82 ± 16 kg, BMI 29.4 ± 3.7 kg/m^2, duration of diabetes 15 ± 10 years, HbA_{1c} 7.5 ± 1%, ABPI 0.73 ± 0.13; seven participants had loss of sensation to 10 g monofilament at two or more sites tested (table 1)) from the diabetes centre, Hairmyres Hospital, and specialist community podiatry clinics in East Kilbride, Scotland during visits for complication screening. Patients with diabetes were selected if ABPI was < 0.9 in the absence of critical ischaemia, and all were naive to specialised footwear. Among the exclusion criteria were a current foot ulcer, the inability to walk unassisted, or a shoe size outside the range of the insoles (< UK size 3 or > UK size 12). Ethical approval was granted by NHS Lanarkshire. Participants provided written informed consent and received no remuneration for participating.

Liqua Care® insoles

Liqua Care® insoles (a patented, Class 1 Medical Device) used in the study were provided by Autonomed Ltd, Wetherby, UK. These patented insoles have a unique design and contain high-viscosity non-toxic liquid housed within a control system thus enabling flow of liquid between compartments which correspond to foot compartments, resulting in redistribution of static and dynamic foot pressure. Liqua Care® insoles are thin enough to be fitted to most footwear and are simply placed within the patient's own footwear after the shoe has been appropriately sized (figure 1). The patient is given a specially prepared advice sheet regarding the wearing of the insoles and this also provides a good opportunity to issue the patient with general footwear advice.

Study protocol

Upon recruitment and under controlled conditions $TcpO_2$ at the apex of both great toes was measured using the Radiometer TCM 400 according to the manufacturer's recommendations (Radiometer Medical, Copenhagen, Denmark). All $TcpO_2$ measurements were made by a single observer. All hosiery was removed, and study participants lay supine for at least 10 minutes before $TcpO_2$ measurements were made to allow foot temperature to stabilise within the same controlled ambient room temperature.

Liqua Care® insoles were then fitted, and the subject given verbal and written advice to wear the insoles for up to 8 hours every day for 2 weeks. During a return visit 2 weeks later, $TcpO_2$ measurements were repeated, and in-shoe pressure measurements were obtained using the F-Scan system according to the manufacturer's recommendations (Tekscan, Boston, MA) to 'map' the plantar pressure distribution on the right foot with the insoles removed, and then with the Liqua Care® insoles refitted.

All F-Scan system measurements were made by a single observer with a sample rate of 50 Hz. Peak pressure tables were produced by averaging all representative strides at the participants normal walking pace over a 15-second period collected without, and then with, the test insoles. This equated to an average of between 15–20 strides per patient walking at their natural pace. The insole area was divided into three regions roughly representing the fore-, mid- and hindfoot. These regions are not anatomically accurate but are felt to correspond appropriately for the purposes of the study.

Statistical analysis

Peak plantar pressure measurement results for each individual are expressed as means. $TcpO_2$ measurements are expressed as absolute values. Results were analysed using paired Student's t-test and statistical significance assumed if $p<0.05$.

Results

Plantar pressures

Individual mean peak pressures measured in all three foot regions without and then with Liqua Care® insoles are demonstrated in table 2. When data from all subjects were analysed together, a 21.5% reduction in mean forefoot pressure was demonstrated (254.6 kPa without, 199.9 kPa with Liqua Care® 95% CI 176.8–222.9 kPa, $p=7.6 \times 10^{-5}$), with no significant change in peak midfoot (85.4 kPa without, 96.4 kPa with Liqua Care® 95% CI 80.3–102.5 kPa, p=0.17) or hindfoot pressures (176.5 kPa without, 173.1 kPa with Liqua Care® 95% CI 162.5–183.7 kPa, p=0.51). There was no effect of gender upon these results. Individual data from a representative subject are shown in figures 2 and 3.

Table 2. Peak foot pressures with and without insoles, and transcutaneous tissue oxygenation before and after using insoles for two weeks

	Peak foot pressures (kPa)						$TcpO_2$ (mmHg)			
	Hindfoot		Midfoot		Forefoot		Before insole		After insole	
ID#	Without	With	Without	With	Without	With	Left	Right	Left	Right
2	177	202	42	73	186	175	36.0	51.8	36.8	57.0
3	144	149	52	76	252	250	40.5	51.8	42.8	53.3
5	144	150	80	92	314	290	52.5	52.5	61.5	51.0
6	208	187	66	64	269	235	59.3	69.8	75.8	69.0
7	175	173	72	62	195	166	51.8	63.0	51.8	64.5
8	152	166	67	73	169	160	62.3	66.0	63.0	65.3
9	202	191	67	75	290	223	40.5	45.8	39.0	46.5
10	125	133	58	94	213	179	46.5	63.8	58.5	74.3
11	86	106	230	175	394	285	53.3	51.8	57.0	49.5
12	174	165	14	32	166	72	54.8	62.3	52.5	49.5
13	216	216	70	78	312	279	60.0	66.8	69.0	61.5
14	155	138	128	122	198	162	69.8	69.0	72.0	59.3
15	280	297	102	104	227	89	62.3	48.0	65.3	55.5
16	131	168	81	86	149	121	62.3	66.0	61.5	66.8
17	175	144	171	294	356	187	61.5	47.3	62.3	65.3
18	144	174	33	94	523	358	51.8	57.8	53.3	57.8
19	152	136	65	80	149	132	54.8	-*	61.5	-*
20	239	205	124	103	237	174	-*	57.0	-*	60.8
21	170	136	86	76	165	126	83.3	-*	87.0	-*
22	253	201	85	101	278	251	55.5	45.0	69.0	48.0
23	204	198	101	71	304	283	45.0	51.8	57.0	53.3
n=21	176	173	85	96	255	200	55.2	57.3	59.8	58.3
	±46#	±41#	±48#	±53#	±93#	±75#	±10.9#	±8.3#	±12.1#	±7.9#

*At enrolment only one $TcpO_2$ sensor available
#Values are mean ± standard deviation
Key: $TcpO_2$ = transcutaneous tissue oxygenation

Transcutaneous tissue oxygenation

$TcpO_2$ measured at the great toe following 2 weeks of Liqua Care® insole use resulted in a mean increase of 2.9 mmHg (95% CI 0.9–5.0 mmHg, p=0.006) compared with baseline (figure 4). This represented a small but significant 5% improvement of transcutaneous tissue oxygenation. There was no effect of gender upon these results. When the first three patients enrolled in the study, there was only one $TcpO_2$ sensor and thus these patients only have unilateral $TcpO_2$ data (table 2). A second sensor was available for all subsequent patients.

Adverse events

One subject experienced a unilateral pedal tinea infection which occurred between study visits, and was felt to be unrelated to the intervention. No adverse events were reported, and the insoles were well tolerated by the remaining participants.

Conclusions

In this study we found that when Liqua Care® therapeutic insoles were worn by individuals with diabetes and vascular insufficiency, peak forefoot pressure was reduced by 21.5%. Additionally, following 2 weeks insole use we observed a 5% improvement in transcutaneous tissue oxygen tension when measured at the great toe under controlled conditions. Together these results suggest that Liqua Care® insoles would be an effective intervention for subjects at risk of foot ulceration.

A particular advantage of Liqua Care® insoles is the slim-line profile which allows insertion into the patients own non-prescription footwear, which itself requires no modification. They are widely available to use 'off the shelf' and are thin enough to fit most types of footwear. These results imply that use of Liqua Care® therapeutic insoles by individuals at risk of

Figure 2. Colour pressure map showing regional foot pressures measured by the F-Scan without and with the Liqua Care® insole in a representative individual (low foot pressure indicated by the blue end of the colour spectrum)

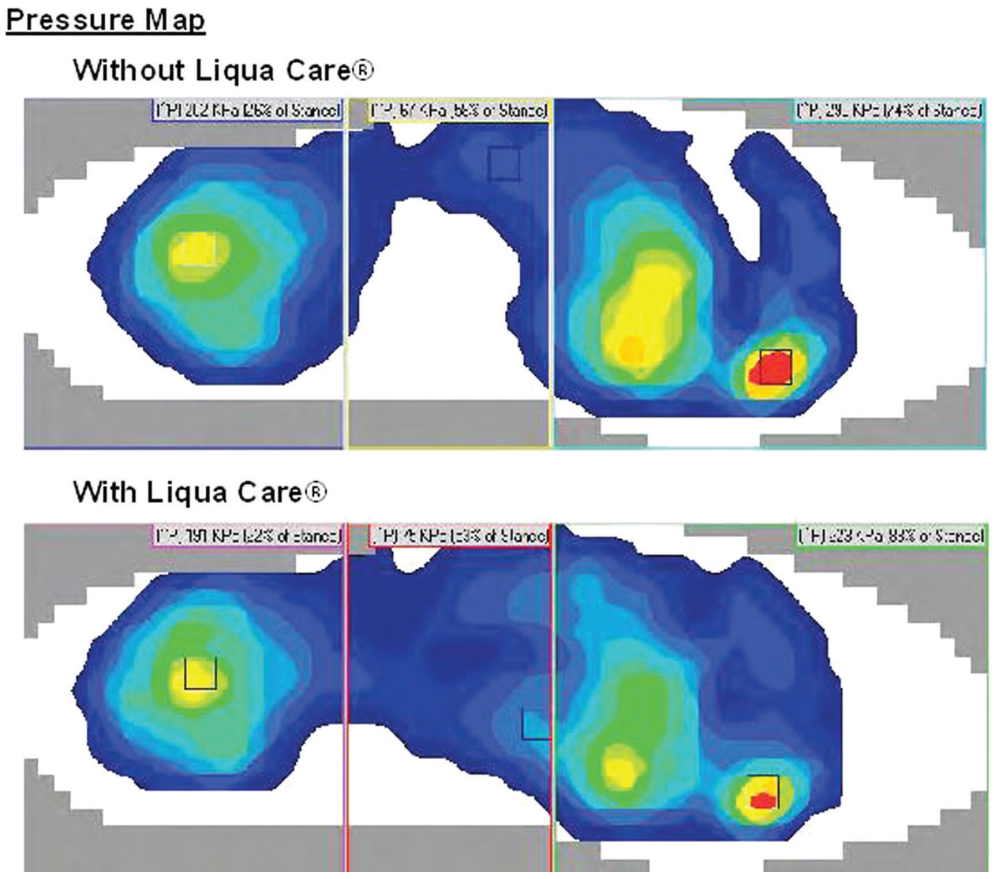


Figure 3. Graph indicating regional peak foot pressure (kPa) without (pink bars), and with (grey bars) the Liqua Care® insole measured in the same representative subject as in figure 2

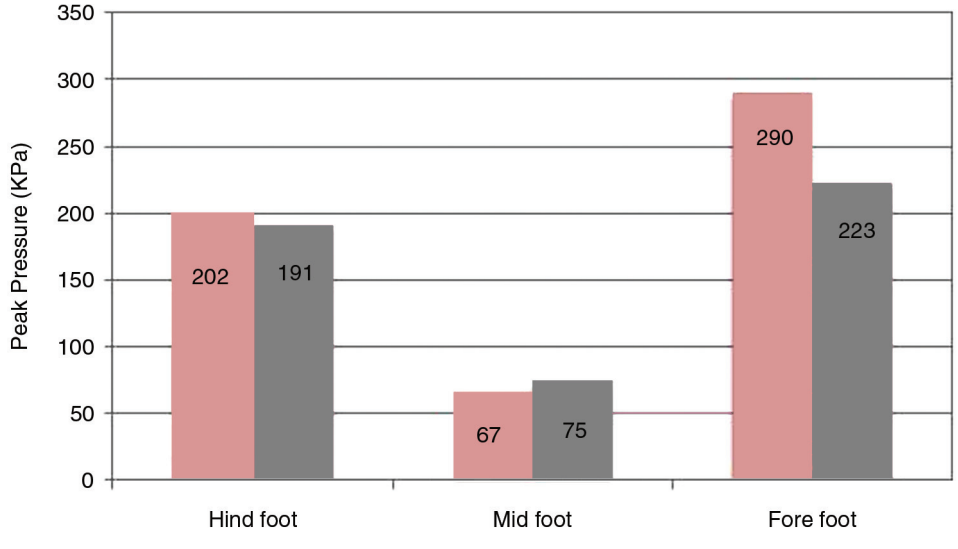
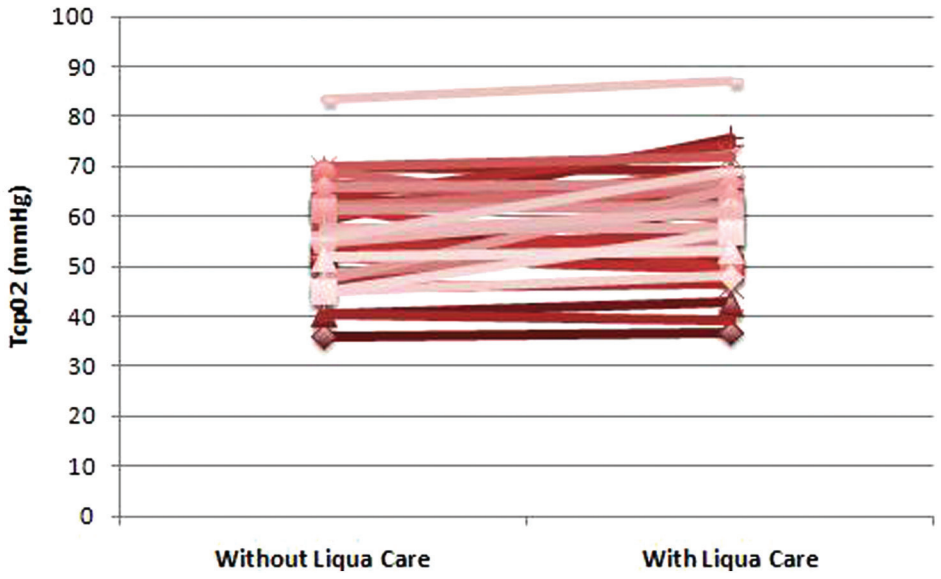


Figure 4. Great toe $TcpO_2$ measurements before, and following 2 weeks of Liqua Care® insole use for each study subject (mmHg)



pedal ulceration can lead to both reduced forefoot pressure and improved tissue oxygenation, both of which are desirable goals in the prevention of pedal ulceration.

Limitations of the current study include the participant selection, which was based on an account of vascular insufficiency. The ability of Liqua Care® insoles to reduce foot pressure in a cohort of individuals with significant neuropathy remains to be determined. In addition, the short duration of the intervention and the single timepoint for measurement of $TcpO_2$ allows no estimation of, or time taken to reach peak effect, or of the durability of the insoles to maintain it. While we believe the observed differences in tissue oxygenation are due to the insoles studied, we did not include a control group with whom direct comparison could be made.

In our study, plantar pressure was measured 'in-shoe', which has been shown to have stronger correlation with ulcer location than other methods of regional foot pressure estimation.[20] The degree of pressure reduction which results from Liqua Care® insole use is similar to that associated with other insoles when used in an identical clinical setting,[17] and also in studies of longer duration where ulcer prevention was the main endpoint. The mean peak forefoot pressure when insoles were used in our study is identical to the value proposed as target peak pressure to prevent re-ulceration in a recent retrospective analysis of a cohort of over 50 individuals,[21] suggesting the potential for Liqua Care® insoles to be used to prevent pedal ulcers.

Here, we have demonstrated increased tissue oxygenation as a consequence of therapeutic insole use for the first time. We propose the unique control system which allows redistribution of liquid gel between compartments inside the insole (and thus redistribution of plantar pressures) leads to increased small muscle activity within the feet. This in turn facilitates improved venous and lymphatic flow, as well as increased delivery of arterial blood to the capillary bed. Although the increase in $TcpO_2$ we observed is small, it is likely to be clinically significant.[13,22] Moreover, the enhanced tissue oxygenation was observed after just 2 weeks insole use. Given the proposed mechanism of action, it is conceivable that wearing the insoles for a longer period of time may be associated with an even greater improvement in tissue oxygen delivery, which will protect against tissue breakdown and ulceration.

In conclusion, Liqua Care® insoles reduce forefoot pressure and improve $TcpO_2$ in a small cohort at risk of foot ulceration. These pilot data would suggest that a larger, randomised and controlled trial conducted over a longer time period is now required to assess the ability of Liqua Care® insoles to prevent new and recurrent pedal ulceration in subjects who are at risk of developing this complication of diabetes.

Author contribution

S. Miller researched data, contributed to discussion and wrote the manuscript, D. Bain researched data and contributed to discussion, T. Siddiqui reviewed, edited and submitted the manuscript, W. Munro researched data and contributed to discussion, R. Hamill and D. Jones researched data, and D. Stang researched data, contributed to discussion and reviewed and edited the manuscript.

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Key messages

Gel-filled (Liqua Care®) insoles:

- reduced forefoot pressure by 21.5%
- increased foot $TcpO_2$ by 5%
- may help in prevention of pedal ulcers

Duality of interest

The authors report no conflict of interests.

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