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Short Reports

Use of Experimental Padded Hosiery to Reduce Abnormal Foot Pressures in Diabetic Neuropathy

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High pressures under the feet of diabetic patients with neuropathy are associated with the development of plantar ulceration. The aim of management is the reduction of such stresses with orthoses and insoles. An American hosiery manufacturer has developed socks designed to reduce stress on athletes' feet, and we report a preliminary evaluation of this technique in the reduction of elevated plantar pressure in 27 neuropathic diabetic patients. With a computerized optical pedobarograph, three footsteps on each side were recorded under three conditions: *1)* barefoot, *2)* wearing the patients' own hosiery, and *3)* wearing experimental patented padded hosiery. The patients' own hosiery did not have a significant effect on plantar pressure, but the experimental hosiery reduced both peak forefoot pressure and the area under the time-pressure curve ($P < .001$) by a mean of 26 and 29%, respectively. We conclude that the experimental hosiery is effective in reducing vertical pressures under the diabetic foot and, in conjunction with established orthotic techniques, may be a useful addition to the treatment of the diabetic patient at risk for foot ulceration. *Diabetes Care* 12:653–55, 1989

Foot ulceration remains one of the most common causes of hospital admission among diabetic patients despite increased research into this problem in recent years (1). Previous studies have confirmed the importance of abnormal pressures and loads under the neuropathic foot in the etiology of foot ulceration, and recurrent ulceration is commonly seen because increased pressures under the metatarsal heads persist after the healing of forefoot ulcers (2). Strategies to reduce the incidence of ulceration have included the use of specialized footwear and insoles that might lead to a redistribution of the abnormal pressures (3). No studies of hosiery as a means of pressure relief have been published; therefore, we have assessed the potential of specially padded hosiery to relieve high pressures in diabetic neuropathic patients with abnormal dynamic foot-pressure studies.

RESEARCH DESIGN AND METHODS

Twenty-seven patients (15 men, 12 women) with diabetes and abnormal plantar pressures (>10 kg/cm^2) took part in the study (4). Their mean age was 54 yr (26–78 yr). Ten patients suffered from neuropathic foot ulcerations, none had significant peripheral vascular disease, all had evidence of peripheral neuropathy, and all were able to walk unaided. Patients were not given advance warning, so that studies were made with patients wearing their normal hosiery in addition to the experimental hosiery. The study received institutional review board approval, and informed consent was obtained from all patients.

Foot-pressure measurements were made with an optical pedobarograph, details of which have been described (4). Dynamic recordings were made of three

footsteps from each foot under three conditions: *1*) barefoot, *2*) wearing their own socks, and *3*) wearing Thor-Lo patented hosiery with experimental acrylic fibers (Thorneburg, Statesville, NC), which has specially designed padding particularly around the heel and forefoot (approximate composition 85% acrylic, 15% nylon).

The areas chosen for comparison were the highest forefoot pressure area barefoot and the first and fifth metatarsal heads. Mean peak pressure and mean area under the time-pressure curve were calculated for each of the test conditions. Peripheral nerve function was assessed by conventional electrophysiological techniques, including peroneal nerve motor conduction velocity and vibration perception threshold with the Biothesiometer (Bio-Medical, Newbury, OH) (2).

Because feet can be considered to be individually at risk in terms of high pressures, the analysis treated each foot as a separate variable. Statistical analysis was conducted with the Amstat statistical package for Amstrad computers (SC Coleman, Ashby-de-la-Zouch, Leics, UK), and standard nonparametric techniques were used (Wilcoxon's matched pairs signed-rank test and Spearman's rank correlation test).

RESULTS

All patients studied had evidence of impaired peripheral nerve function. Mean ± SD peroneal motor conduction velocity was 37.3 ± 5.4 ms^{-1} (normal >40; unrecordable in 4 patients), and vibration perception threshold was 33.4 ± 13.7 (normal <20; unrecordable values were 51).

For technical reasons, 1 footstep was not satisfactorily recorded; therefore analysis was of the remaining 53 footsteps. There was no difference in mean peak pressure or area under the time-pressure curve between barefoot measurements and those made with the patients' own hosiery. In contrast, the patented experimental hosiery resulted in a large reduction in both parameters (Table 1). Mean reduction of the highest peak pressure (relative to barefoot pressures) was 26%, and reduction in the area under the corresponding time-pressure curve was 29%. The highest pressures tended to be associated with the greatest pressure reductions, with a significant correlation between the values (r = .51, $P < .001$). Of 27 subjects, 26 stated they would be happy to wear such hosiery on a long-term basis.

DISCUSSION

We have previously shown that diabetic neuropathic subjects with a history of foot ulceration have abnormally high pressures under the feet during walking, and it appears that the combination of insensitivity and abnormal loading leads to ulceration (2,6). In this study, we demonstrated that a significant reduction in dynamic foot pressure can be achieved when wearing the experimental padded patented hosiery compared with barefoot gait or walking while wearing usual hosiery. To avoid bias with the latter comparison, patients were not given advance warning of the study but were invited to participate at routine clinic visits. No pressure reduction was seen with normal hosiery, whereas the provision of high-density protective pads under pressure-bearing areas in many cases reduced loading into the normal range. Patients with very abnormal loading experienced greater reduction of pressure with the special hosiery, although in many subjects who experienced such abnormal pressures that they were virtually walking on their metatarsal heads, some reduction was seen, but the result remained abnormal.

Previous studies have attempted to reduce or redistribute pressures under the diabetic foot with various orthoses, insoles, or custom-designed footwear (3,7). More recently, there has been increasing interest in the use of socks to protect the feet in various sporting activities. However, although special socks are widely used in sports, to our knowledge, there is no previous report of their use in diabetic foot care. Special socks may be cosmetically more attractive than extra-depth or custom-designed footwear to the patient with insensitive feet in whom compliance may present a major problem.

As in previous studies, we measured vertical pressures

TABLE 1
Mean pressures and areas under time-pressure curve

	Mean peak pressure (kg/cm^2)			Mean area under curve ($kg \cdot cm^{-2} \cdot s$)		
		Metatarsal heads			Metatarsal heads	
Test condition	Highest	First	Fifth	Highest	First	Fifth
Barefoot	14.25 ± 0.55	8.24 ± 0.61	6.56 ± 0.75	5.02 ± 0.27	2.94 ± 0.25	2.21 ± 0.31
Own hosiery	14.08 ± 0.85	8.0 ± 0.96	7.0 ± 0.89	4.97 ± 0.45	3.07 ± 0.47	2.30 ± 0.35
Experimental	10.47 ± 0.54*	5.81 ± 0.43*	4.73 ± 0.48†	3.45 ± 0.20*	2.03 ± 0.18†	1.42 ± 0.15†

Mean ± SE peak forefoot pressure (normal <10 kg/cm^2) and area under time-pressure curve for each of the test conditions. Values are given for highest barefoot pressure area and the 1st and 5th metatarsal heads.
*$P < .001$; †$P < .01$.

at the sock-floor interface, although the optical system used is able to give a greater spatial resolution than other systems currently in use (2). Other systems, such as the electrodynogram, which uses small transducers, are able to measure pressure at the foot-insole interface but at a lower resolution. With such a system, Smith et al. (7) recently confirmed that significant reductions in pressures at the foot-insole interface were achieved with a shock-absorbent inlay (Professional Protective Techniques). Therefore, it is possible that measurement at either interface will give similar results. It is also likely that shear stresses are an important factor in the development of foot ulcers and that these may be modified by hosiery, but there is no satisfactory way of measuring these forces.

There is an urgent need to define effective strategies to protect the high-risk diabetic foot because lower-extremity amputations remain 15 times more common among diabetic subjects (1,8). From this preliminary study, we conclude that the use of protective hosiery may be a useful, acceptable, and inexpensive addition to existing methods for protecting the insensitive foot from abnormal pressures and loads. Compliance from diabetic subjects would probably be high with special socks, although longitudinal studies are needed to assess the effects of long-term use on the pressure-relieving properties. Use of padded socks may give additional benefit to patients who already require special shoes.

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REFERENCES

1. Boulton AJM: The diabetic foot. *Med Clin N Am* 72: 1513–30, 1988
2. Boulton AJM, Hardisty CA, Betts RP, Franks CI, Worth RC, Ward JD, Duckworth T: Dynamic foot pressure and other studies as diagnostic and management aids in diabetic neuropathy. *Diabetes Care* 6:26–33, 1983
3. Coleman WC: Footwear in a management program of injury prevention. In *The Diabetic Foot*. Levin ME, O'Neal LW, Eds. St. Louis, MO, Mosby, 1988
4. Betts RP, Franks CI, Duckworth T: Analysis of pressures and loads under the foot. 1. Quantification of the static distribution using the PET computer. 2. Quantification of the dynamic distribution. *Clin Phys Physiol Meas* 1:101–24, 1980
5. Boulton AJM, Betts RP, Franks CI, Ward JD, Duckworth T: The natural history of foot pressure abnormalities in neuropathic diabetic subjects. *Diabetes Res* 5:73–77, 1987
6. Masson EA, Hay EM, Stockley I, Veves A, Boulton AJM: Abnormal pressure alone does not cause foot ulceration. *Diabetic Med* 6:424–26, 1989
7. Smith L, Plehwe W, Yue DK, Turtle JR: Electrodynogram in objective assessment of bearing pressures in the feet of diabetic patients. *Diabetes Res Clin Pract* 5 (Suppl. 1):S312, 1988
8. Bild DE, Selby JV, Sinnock P, Browner WS, Braveman P, Showstack JA: Lower-extremity amputation in people with diabetes: epidemiology and prevention. *Diabetes Care* 12:24–31, 1989