current

Pedorthics

The Official Publication of the Pedorthic Footcare Association

Sensorimotor and Gait Training

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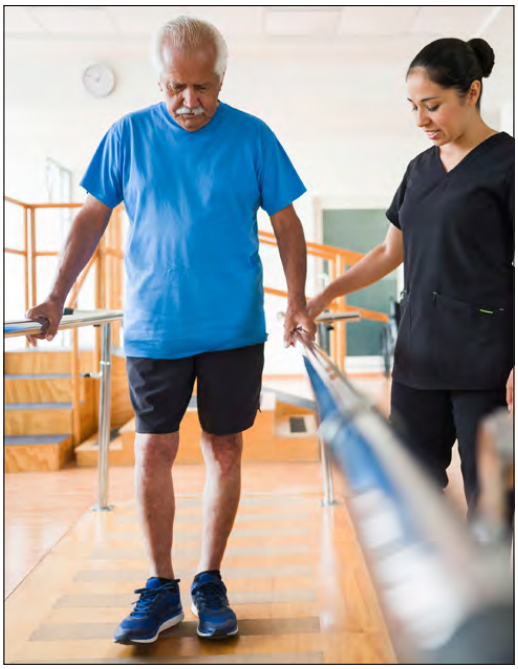

14 | **Sensorimotor and Gait Training:** Improved proprioception, nerve function, and muscular activation in patients with diabetic peripheral neuropathy — *a randomized control trial*

BY IRSHAD AHMAD, SHALINI VERMA, MAJUMI M. NOOHU, MOHD.YAKUB SHAREEF, AND M. EJAZ HUSSAIN

The lack of proprioception in patients with peripheral neuropathy, including that caused by diabetes, is a common finding in many of our patients. In this study, the authors are able to correlate sensorimotor training with increases in overall stability and particularly in muscles that stabilize the ankle. This may be the perfect time to team up with a local physical therapist to utilize their expertise. The increased stability may make it possible for the patient to tolerate your treatment, thereby reducing the negative effects of the disease on the foot. A win for everyone!

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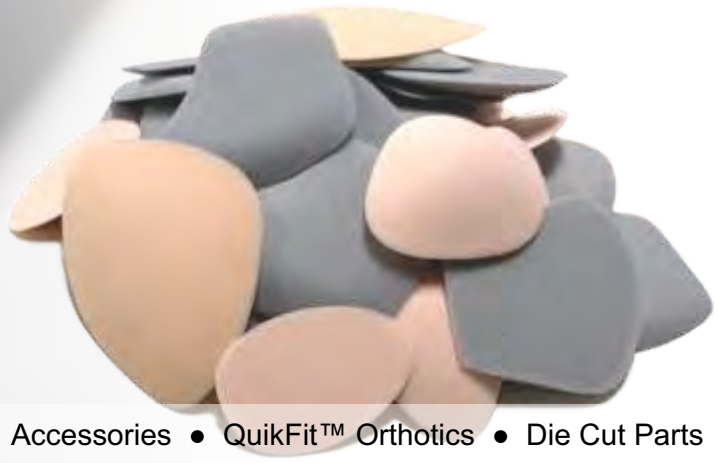

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current Pedorthics

September-October 2020
Volume 52, Issue 5

Features

40 | Diabetic Foot Australia guideline on footwear for people with diabetes

BY JAAP J. VAN NETTEN, PETER A. LAZZARINI, DAVID G. ARMSTRONG, SICCO A. BUS, ROBERT FITRIDGE, KEITH HARDING, EWAN KINNEAR, MATTHEW MALONE, HYLTON B. MENZ, BYRON M. PERRIN, KLAAS POSTEMA, JENNY PRENTICE, KARL-HEINZ SCHOTT, AND PAUL R. WRAIGHT

The authors of this paper include some of the most influential experts on care of the foot for patients with diabetes who are practicing today. They combined efforts to update the guidelines published in Australia in 2013. This paper not only includes the guidelines themselves, but also documents the rationale behind each one. While there is some discussion in the paper that refers to Australia specifically, it is minimal making this useful here in the States as a handout for patients and referral sources.

Illustration adapted from: https://images.app.goo.gl/Jw5ANR5RKVRgQJnFA

"Appropriate footwear is important for all people with diabetes, to prevent foot ulceration and reduce the burden of diabetic foot disease. "

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CHRIS COSTANTINI
Executive Editor
editor@pedorthics.org

Hello Everyone! It has been awhile since I have written to you. I decided that this was a fine time to do so. I am very excited about this issue!

This issue of Current Pedorthics:

We have a great research article that will give you to have another reason to team up with local physical therapists. You can maximize the safety of patients that you treat who have limited proprioception. We also decided to publish the shoe and insole guidelines for patients that are suffering from diabetes that were developed in Australia. The material contained in them can be used for marketing and to help you promote your pedorthic practice.

New LMS Products:

Article – Efficacy of Arch Taping as a Symptomatic Treatment for Plantar Fasciitis – Plantar fasciitis has been one of the more common foot conditions managed with arch taping as it was originally introduced by Dr. Ralph Dye in the 1940s.

Webinar – Weird Diagnoses - You Have What??? – This program explores some of the fringe diagnoses that pedorthists will encounter if they practice long enough & look at how to treat them pedorthically.

Webinar – Pedorthic Management of Forefoot Deformities and Conditions – This program reviews causes of and pedorthic treatment options of commonly forefoot deformities. many tried and true pedorthic solutions are covered as well as some new and innovative modalities.

PFA Event Updates:

PFA Virtual Symposium:

Missing your PFA fix this November? The PFA Virtual Symposium will provide you with the knowledge you need to advance your career and grow your practice. General sessions will feature topics ranging from Pedorthic Treatment Protocols to 3-D Printing to Pedorthic Care of the Athlete and everything in between! So, plan to join us for 10 hours of CEU's and an informative day where you will learn skills you can apply to your practice.

The O&P Medicare/Insurance Billing & Documentation Workshop:

These live session Workshops will provide detailed information on the billing and documentation process for both Medicare and private insurance. Participants will gain knowledge of all necessary documentation, reviewing physician documentation, submitting claims, and reviewing denials.

Register: The O&P Medicare/Insurance Billing & Documentation Workshop – October 2nd-3rd 2020 – Hyatt Place – Atlanta Airport South, College Park, Georgia

Register: The O&P Medicare/Insurance Billing & Documentation Workshop – January 15th-16th 2021 – Saddlebrook Resort & Spa, Wesley Chapel, Florida

61st Annual Symposium and Exhibition:

Announcing *PFA's 61st Annual Symposium and Exhibition* on July 22nd-24th 2021 in Tampa Florida! Please stay tuned for updated information and links to the 61st Registration Website (SOON) to save your space!

I hope you enjoy this issue of Current Pedorthics Magazine. From all of us here at your PFA, may you and your family be safe and well.

Thank you,

■ Christopher Costantini
Executive Editor

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PEDORTHIC FOOTCARE ASSOCIATION

ABOUT PFA

The Pedorthic Footcare Association (PFA), founded in 1958, is the not-for-profit professional association which represents the interests of the certified and/or licensed pedorthist and supports the pedorthic profession at large.

Through PFA's efforts, *pedorthics* – the management and treatment of conditions of the foot, ankle, and lower extremities requiring fitting, fabricating, and adjusting of pedorthic devices – is a well-established allied health profession which makes an invaluable contribution to public health.

MISSION

PFA's mission is to enhance the effectiveness and efficiency of credentialed providers of lower extremity pedorthic modalities through education; increase the demand for services through marketing; and promote the right to practice through government affairs activities.

Pedorthic Footcare Association

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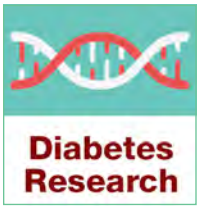
Irshad Ahmad, Shalini Verma, Majumi M. Noohu, Mohd.Yakub Shareef, and M. Ejaz Hussain

The research for this study was conducted by:
• Diabetes Research Group, Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia (A Central University), New Delhi, India
• Human Performance Lab, Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia (A Central University), New Delhi, India
• Ansari Health Centre, Jamia Millia Islamia (A Central University), New Delhi, India.



Jaap J. van Netten, Peter A. Lazzarini, David G. Armstrong, Sicco A. Bus, Robert Fitridge, Keith Harding, Ewan Kinnear, Matthew Malone, Hylton B. Menz, Byron M. Perrin, Klaas Postema, Jenny Prentice, Karl-Heinz Schott, and Paul R. Wraight

The research for this study was conducted by:
• School of Clinical Sciences, Queensland University of Technology, Brisbane, QLD Australia
• Diabetic Foot Australia, Brisbane, QLD Australia
• Wound Management Innovation Cooperative Research Centre, Brisbane, QLD Australia
• Allied Health Research Collaborative, Metro North Hospital & Health Service, Brisbane, QLD Australia
• Southern Arizona Limb Salvage Alliance (SALSA), Department of Surgery, University of Arizona College of Medicine, Tucson, AZ USA
• Department of Rehabilitation, Academic Medical Center, University of Amsterdam, Amsterdam Movement Sciences, Amsterdam, the Netherlands
• Vascular Surgery, The University of Adelaide, Adelaide, South Australia Australia
• University Dean of Clinical Innovation, Professor of Wound Healing Research, Cardiff University, Cardiff, UK
• High Risk Foot Service, Liverpool Hospital, South Western Sydney Local Health District, Sydney, NSW Australia
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• La Trobe Rural Health School, College of Science, Health and Engineering, La Trobe University, Bendigo, VIC Australia
• Department of Rehabilitation Medicine, University of Groningen, University Medical Center Groningen, Department of Rehabilitation Medicine, Groningen, the Netherlands
• Wound Consultant, Trojan Health, Perth, WA Australia
• School of Health and Human Sciences (Pedorthics) Southern Cross University Gold Coast Campus, Bilinga, QLD Australia
• Diabetic Foot Unit, Royal Melbourne Hospital, Melbourne, VIC Australia

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For more details, contact ***Current Pedorthics*** magazine at **(229) 389-3440** or by email at: **editor@pedorthics.org** for additional upcoming special interest topics, guidelines and other ideas you may want to discuss as topic ideas beneficial to health care, patient care and all areas of interest in the pedorthics practice and other associated industries.

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Product Information:

Efficacy of Arch Taping as a Symptomatic Treatment for Plantar Fasciitis

Plantar fasciitis has been one of the more common foot conditions managed with arch taping as it was originally introduced by Dr. Ralph Dye in the 1940s.

Weird Diagnoses: You Have What???

This program explores some of the fringe diagnoses that pedorthists will encounter if they practice long enough & look at how to treat them pedorthically.

Pedorthic Management of Forefoot Deformities & Conditions

This program reviews causes of and pedorthic treatment options of commonly forefoot deformities. many tried and true pedorthic solutions are covered as well as some new and innovative modalities.

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New Products on PFA's Learning Management System (LMS) for Continuing Education!

For Immediate Release:

The current update is one from the PFA Article Series and two from the PFA Webinar Series. The article contains the excerpt from a *Current Pedorthics* issue and each webinar containes a video of the speakers and slide presentation. When completed, both have a test to take where you can attain CEUs and keep track of your progress towards your certification. (*see current ad pg.7*).

Simply log in with your PFA membership information and earn your CEU's! Go to the *PFA Learning Management System* by typing the link in your browser or clicking below:

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O&P Medicare and Insurance Billing & Documentation Workshop - Two Live Sessions

For Immediate Release:

PFA will be conducting two 2-day O&P workshops. One session will be October 2nd-3rd, 2020 in College Park, GA and the second will be January 15th-16th, 2021 in Wesley Chapel, Florida.

The featured speakers are Matt Almeida, *PFA President* and Althea Powell-Chandler *PFA Vice-President*. This program will provide detailed information on the billing and documentation process for both Medicare and private insurance (*see: ad pg13*).

Please watch for PFA email and at the PFA website for additional information.
https://www.pedorthics.org/page/OP_Workshop

ABC CredCast - Amazing Resources for Your Limb Loss Patients

New Episode 28:

Look like a hero with your limb loss and limb difference patients after listening to this episode! Jim sits down with Caitlyn Hurley, Manager of the Amputee Coalition's National Limb Loss Resource Center to discuss the many valuable and free resources available to the limb loss community, many of which you may not be aware

Amazing Resources for Limb Loss Patients:
https://www.abcop.org/news-events/Pages/CredCast.aspx

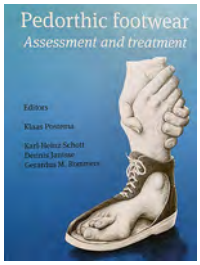
COVID-19 information page on PFA's website

For Immediate Release:

The PFA headquarters staff is continuing to work hard and make sure you have the pertinent information you need regarding your practice.

The COVID-19 situation presents a very dynamic and ever updating situation, so we feel free to email us with something you think should be there at: *info@pedorthics.org*

PFA's COVID-19 Information Page:
https://www.pedorthics.org/page/COVID_Resource



New Pedorthic Textbook!

For Immediate Release:

The Pedorthic Footcare Association is proud to announce that it is the exclusive distributor the important new pedorthic textbook, "*Pedorthic Footwear: Assessment and Treatment*".

This will become an important resource for pedorthic students and practitioners. With more than 550 pages, written and compiled by PFA speaker and longtime member, Dennis Janisse, C.Ped and a prominent team from across the globe!, this text covers everything from the basic sciences of anatomy, pathology and physiology to cause and treatment of common disorders the pedorthist sees every day in practice.

The material is written in simple, easy to understand language and is packed with photos and illustrations. Full review coming soon, but don't wait, get yours now before the rush. Available in the PFA store now (*see: ad pg19*):

Pedorthic Footwear: Assessment and Treatment textbook in the PFA Store:
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The O&P Medicare and Insurance Billing & Documentation Workshop

UPCOMING LIVE EVENTS:

October 2nd-3rd, 2020
Hyatt Place - Atlanta Airport South,
College Park, GA

January 15th-16th, 2021
Saddlebrook Resort & Spa
Wesley Chapel, Florida

Matt D. Almeida, Ms, CPA, CMA, MFP, BOCO, BOCPD

Description: Program will provide detailed information on the billing and documentation process for both Medicare and private insurance. Participants will gain knowledge on all necessary documentation, reviewing physician documentation, submitting claims, and reviewing denials.

The student will learn best practices from fellow providers that have successfully cleared obstacles common to not receiving prompt reimbursement.

Students will leave the course with a better understanding of the billing, coding, and documentation process better equipping them to handle billing and documentation within their practice.

Althea Powell-Chandler, C.Ped, LPed

For more information:

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Sensorimotor and Gait Training

Improved proprioception, nerve function, and muscular activation in patients with diabetic peripheral neuropathy

— A randomized control trial —

Abstract

Objectives: To examine the effect of sensorimotor and gait training on proprioception, nerve function, and muscle activation in diabetic peripheral neuropathy (DPN) patients.

Methods: Thirty-eight (25 male and 13 female) participants with DPN were selected and randomly allocated to intervention and control group. Participants in the intervention group were provided sensorimotor and gait training for eight weeks (3 days/week) along with diabetes and foot care education; participants in the control group received diabetes and foot care education only. Outcome measures involved proprioception, nerve conduction studies of peroneal and tibial nerve, and activation of lower limb muscles and multifidus while standing with eyes open and eyes closed, and treadmill walking.

Results: Mixed ANOVA revealed significant time effect and time×group interaction of proprioception in all four directions ($p<0.05$). The conduction velocity of peroneal nerve revealed significant time effect ($p=0.007$) and time×group interaction ($p=0.022$). Interaction effect was found to be significant for medial gastrocnemius and multifidus while standing with eyes open as well as with eyes closed ($p\leq0.004$). Only multifidus showed significant group ($p=0.002$) and interaction effect ($p=0.003$) during walking.

Conclusion: Sensorimotor and gait training is an effective tool for improvement of proprioception and nerve function. It benefits muscle activation around ankle and multifidus during postural control and walking in DPN patients.

Irshad Ahmad, Shalini Verma, Majumi M. Noohu, Mohd.Yakub Shareef, and M. Ejaz Hussain

Introduction

Diabetic peripheral neuropathy (DPN) is the most common complication associated with diabetes mellitus, affecting sensory and motor peripheral nerves. Loss of sensory nerve function results a decrease in sensory inputs sensitivity from the extremities [1-3], while loss of motor axons with insufficient re-innervation related to muscle strength deficit and atrophy of lower limb muscles [4]. Somatosensory information from foot, and proprioception are key determinants for motor control during balance and gait. Somatosensory loss in older patients with peripheral neuropathy is associated with greater proprioception thresholds [5,6]. Also, researchers have observed decrease in the compound motor nerve amplitude [5,7], lower conduction velocity [7-9], and increase in the latency [10] in DPN patients, in comparison to healthy controls. Loss of proprioception and motor nerve impairment deteriorate muscle performance during static and dynamic function [11,12].

Both balance and gait are a complex interplay of neural and muscular actions coordinated with skeletal functions. An age-related increase in the muscle activity during static and dynamic postural tasks and gait has been reported owing to decrease in the somatosensory inputs from feet and legs [13-15]. Study showed increase in muscle activity during postural task in DPN patients [16]. The greater muscle activation of agonist as well as antagonist muscles acts as a balance maintaining strategy during static stance or in response to perturbations during dynamic task [14,15,17]. This compensatory mechanism of increased joint stiffness enhances stability around the joint.

However, there are inconsistent results in DPN patients regarding muscle activation

"Sensorimotor training is considered to be a global approach for balance training."

Photo: @iStock.com/Nattakorn Maneerat

pattern while walking. Some researchers report a reduction in the electromyographic peak activation of tibialis anterior, gastrocnemius, and vastus lateralis [18-21], while others have observed no difference in muscle activation in DPN patients in comparison to controls [21-23]. Additionally, some researchers have also found an increase in the activity of tibialis anterior [18,21]. Also, prolonged duration of activity of lower limb muscles indicate co-contraction of these muscles for the stabilization of ankle joint and improvement of foot stability during foot flat to mid-stance [19,20,23]. Although Akashi et al. found no difference in the coactivation of tibialis anterior and lateral gastrocnemius in DPN patients as compared with control [20].

Sensorimotor training is considered to be a global approach for balance training. It emphasizes the sensorimotor system function as one unit, and works on enhancing sensory inputs and proper recruitment patterns of various muscles in maintaining joint stability, regulating the movement through central nervous system (CNS) [24]. Any imbalance in the muscles responsible for postural control leads to movement impairments and ultimately changes the motor programming in CNS. To correct these impairments, sensorimotor exercises first facilitate sensory inputs (proprioceptive and somatosensory structures), then corrects muscle imbalance and finally facilitates correct motor programming [24]. Along with improvement in balance and spatiotemporal parameters of gait, balance exercises as a part of sensorimotor training have also been shown to improve trunk proprioception in DPN patients [25]. However, there is a lack of studies about the effect of these exercises on the nerve function and muscular activity of lower limb muscles.

Evidence shows that aerobic [26-28] and tai chi exercises [29] modulate the nerve function in DPN patients. Balducci et al. found that simple exercises as brisk walking modify the natural history of the DPN [30]. But there is paucity of knowledge showing the effect of sensorimotor and gait training on neuromuscular functions. Our study was undertaken to examine the effects of sensorimotor and gait training on proprioception, peroneal and tibial nerve function, and electromyographic activity of the lower limb and trunk muscles during postural tasks and treadmill walking.

Materials and methods

Clinical trial was registered in the Clinical Trials Registry - India, National Institute of Medical Statistics (Indian Council of Medical Research) and approved by the Institutional Ethics Committee, Jamia Millia Islamia (JMI), New Delhi. Subjects were recruited during March 2016 to December 2017. The procedures were explained to the subjects, and written informed consent was obtained from each patient before the procedures began. A preliminary investigation was completed in order to verify the participation criteria which included anthropometric, demographic measures and clinical data.

Participants

The eligibility criteria were: male and female subjects aged between 45 and 75 years; diagnosed diabetes mellitus type 1 or 2 for at least 7 years; BMI was between 18.5 and 29.9 kg/m2; subjects had scored more than 2/13 points in the Michigan neuropathy screening instrument (MNSI) questionnaire (Appendix 1), indicating the presence of at least two DPN symptoms [31]; scored greater than 1/10 point scale of MNSI physical examination (*Appendix 1*), including

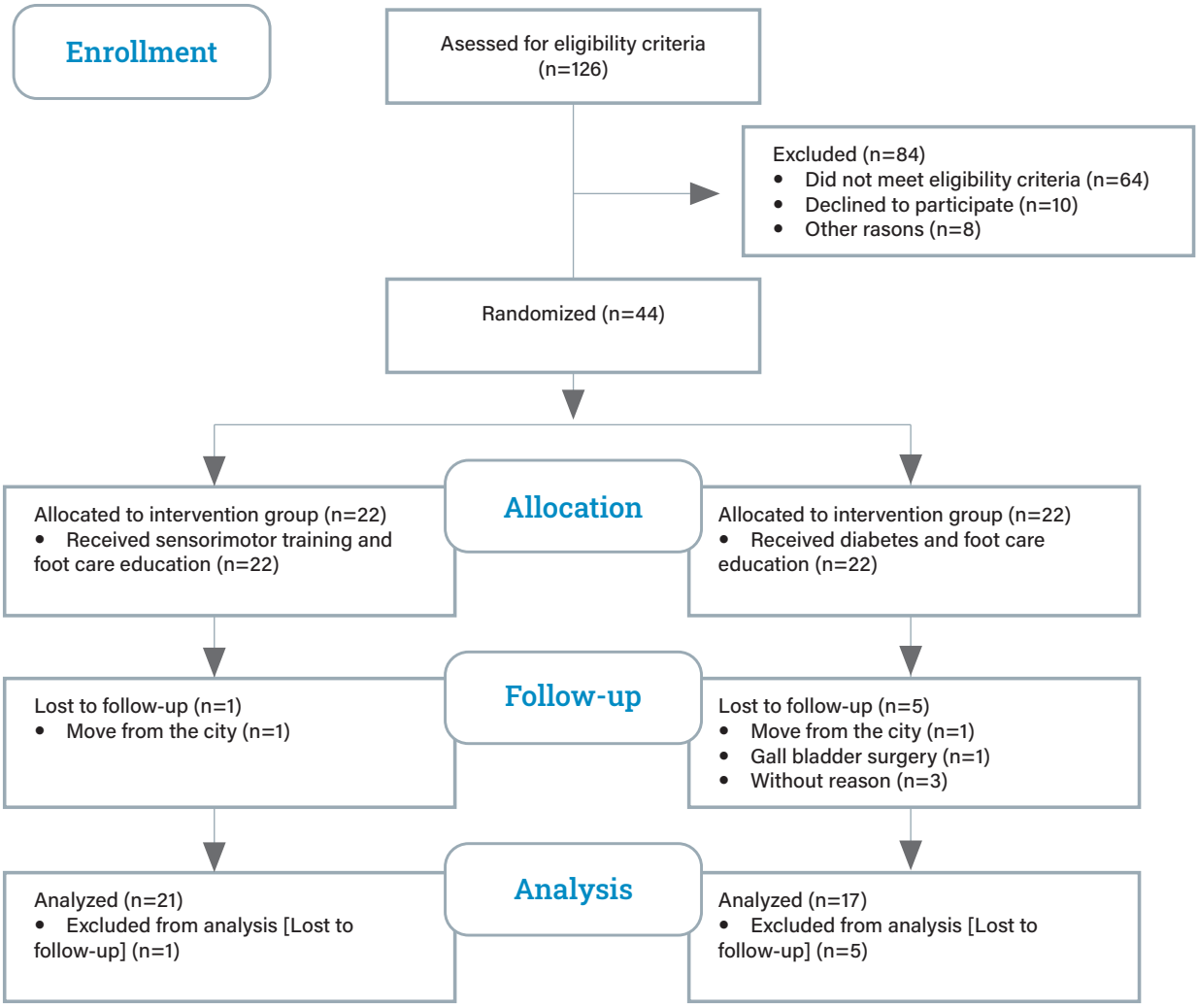

Figure 1: Flow chart of the patients participated in the study.

impaired vibration perception [32]; without any episode of plantar ulceration; no partial or total amputation; and ability to walk independently in the laboratory. Patients were excluded from the study if they had any other neurological impairment; any major vascular complication; severe retinopathy; severe nephropathy; severe musculoskeletal impairment to lower limb; cardiovascular complication; and been receiving any supervised physical intervention [32].

The participants were recruited from (a) Diabetic Centre, Ansari Medical Centre, JMI, (b) Out Patient Department Clinic, Centre for Physiotherapy and Rehabilitation Sciences (CPRS), JMI, and (c) advertisement through pamphlet distribution and JMI website.

All subjects went through an assessment to confirm eligibility. Subsequently, the patients went through the baseline measurement. All identifiable information on the consent form and demographic/injury history questionnaire was kept confidential by assigning a number to each subject. Patients allotted to the intervention group were treated in the outpatient department of the CPRS, JMI.

Design

The study was a two-arm, parallel group randomized controlled trial with single blinding (blinding of outcome assessor). Subjects were randomly allocated to either of the two groups using computer generated random numbers. Subjects allocated to the intervention group received sensorimotor and gait training along with diabetes and foot care education whereas subjects in the control group received diabetes and foot care education only. Both groups were assessed at baseline and after eight weeks of the trial. Enrolment and assignment of participants were done by an investigator who was neither part of assessment of outcome measures nor of implementation of exercise or education. Study design is presented in *Figure 1*.

Interventions

Sensorimotor and gait training

The exercise was conducted thrice a week (alternate days with gap not exceeding more than 48 hours) for eight weeks (total 24 sessions). Each session comprised 10 minutes of warm-up, followed by 50-60 minutes of exercise, followed by 5-10 minutes of cool down. Warm-up exercise included cycle ergometer or treadmill at intensity of 40-50% maximal heart rate [33]. Heart rate was monitored using heart rate monitor (Polar Electro, RS 400, Kempele, Finland). Sensorimotor and gait training comprised wall slides, bridging exercises, prone plank, sit to stand, wobble board exercises, one leg stance, heel and toe raise, tandem stance gradually progressed to different grades using unstable surface (Thera Band® Stability Trainer) and gait training (different patterns of walking) (*Appendix 2 and 3*). Following the training session, subjects performed cool-down exercises, which included deep breathing, abdominal breathing and mild stretching. Their participation in the exercise was modified, postponed, or stopped based on the current guidelines of American Diabetes Association. The exercise level was increased after every two weeks, but if the subject was not able to perform at the next level, their exercise level was maintained at the current level.

Materials

An oval-shaped foam (TheraBand® Stability Trainer of soft green, blue and grey color), round shaped foam (TheraBand® Stability Trainer of soft blue and silver color), bosu ball (TheraBand®), wobble board (bi-directional and multidirectional TheraBand®) and gym ball (red, green, and blue color TheraBand®) made up of polyurethane foam were used.

Diabetes and foot care education

Sessions on diabetes and foot care education was conducted once every two weeks for 30 minutes. It comprised material to understand diabetes, diabetes management and foot care guidelines. The education was provided by professional physiotherapist specialized in diabetes care.

Outcome measures

Proprioception

Proprioception was examined using Pedalo®-Sensamove Balance Test Pro with Miniboard. Miniboard comprised of the circular board with hemispherical shaped sensors placed below the board. It is based on the method of adjustment where the difference between adjustable stimulus and reference stimulus is recorded [34]. Prior to the actual testing, patients were familiarized with the testing procedure. They were asked to stand on the miniboard with the cushion placed below the board. Then, the subjects were asked to

tilt maximally in four different directions (front, back, right and left). The reference stimulus lies within the maximal tilting angle. Each subject was asked to move his/her center of pressure on a colored spot with the help of marker displayed on a screen and to remember the spot. Then the subject was asked to reach the spot without access to the marker. The height of the screen was kept at the eye level. The difference in the angle was measured between the reference stimulus and the actual position. Measurements in all four directions were taken (Pedalo®-Sensamove Balance Test Version 2.2 User Guide). The reliability of the device has been previously reported in older subjects with ICC value 0.91 [35].

Neurophysiological assessment

Nerve conduction studies were carried out for deep peroneal and tibial nerve as recommended by Misra and Kalita [36] and

Table 1: Demographic characteristics.

Variables	Intervention group	Control group	Independent t-test (p-value)	Mann-whitney U test (p-value)
N (M/F)	21 (15/6)	17 (10/7)	-	-
Age (year)	60.33±8.48	57.24±8.85	0.279	-
Height (cm)	164.31±8.59	161.08±9.12	0.271	-
Weight (kg)	66.52±13.22	67.98±12.05	0.727	-
BMI (kg/m^2)	24.51±3.22	26.2±3.71	0.142	-
Diabetic duration (year)	13.69±6.15	14.11±6.04	0.831	-
HbA1C (%)	8.03±1.21	9.15±1.53	0.017*	-
RBG (mmol/L)	178.38±60.37	203.24±50.23	0.183	-
Medication (Oral/Insulin/Both)	13/3/5	10/0/7	-	-
No. of comorbidities [a]	0 [0;1]	1 [0;1]	-	0.835
Smoker or tobacco intake (Y/N)	4/17	7/10	-	-
No. of falls [a]	0 [0;1]	1 [0;1]	-	0.494
MNSI (Q) [a]	4 [3;5.5]	4 [3;6]	-	0.643
MNSI (Ph) [a]	2.5 [2.25;3.75]	2.5 [1.5;3.5]	-	0.32

M: Male; F: Female; BMI: Body mass Index; HbA1C: Glycosylated hemoglobin; RBG: Random blood glucose; MNSI: Michigan neuropathy screening instrument. [a]: median [inter quartial range]; *: significant difference.

Table 2: Baseline comparison of all variables.

Variables	Intervention group (n=21)	Control group (n=17)	Independent t-test (p-value)	Mann-whitney U test (p-value)
Proprioception (angle difference)				
Front	6.50±3.42	9.07±3.51	0.029*	-
Back	10.41±5.41	9.42±6.96	0.625	-
Left	10.07±5.81	9.55±4.71	0.769	-
Right	8.75±5.17	7.87±6.18	0.633	-
Nerve conduction studies				
Peroneal nerve				
Latency (msec)	4.19±1.20	4.12±1.32	0.87	-
Amplitude (mV)	4.44±2.21	4.45±1.85	0.988	-
Duration (msec)	10.32±2.02	10.61±2.80	0.713	-
NCV (m/sec)	38.37±6.62	36.37±7.90	0.401	-
Tibial nerve				
Latency (msec)	4.80±1.13	4.59±0.79	0.515	-
Amplitude (mV)	6.74±3.83	6.12±3.89	0.629	-
Duration (msec)	8.04±1.34	7.92±2.02	0.829	-
NCV (m/sec)	37.94±7.35	38.39±11.69	0.885	-
Standing with eyes open (%MVIC)				
TA	9.63±6.34	10.03±5.54	0.841	-
MG	47.57±26.53	43.96±23.38	0.663	-
VL	15.04±8.44	13.86±9.12	0.681	-
MF	26.39±13.34	23.58±11.50	0.497	-
Standing with eyes closed (%MVIC)				
TA	24.38±14.07	25.98±10.29	0.697	-
MG	73.85±35.55	77.30±39.63	0.779	-
VL	25.73±13.57	21.69±14.39	0.381	-
MF	37.20±19.65	35.57±16.70	0.788	-
Treadmill walking (%MVIC)				
TA	35.13±15.02	31.09±7.84	-	0.736
MG	90.98±38.78	99.84±40.20	-	0.386
VL	59.70±34.56	60.26±40.16	-	0.918
MF	46.85±23.17	54.02±25.11	-	0.284
Co-contraction index (TA-MG)				
Stand (eyes open)	12.67±8.94	13.62±8.70	-	0.567
Stand (eyes closed)	35.34±24.39	34.18±13.73	0.863	-
Gait	52.39±29.32	42.23±12.48	-	0.509

NCV: Nerve conduction velocity; MVIC: Muscle voluntary isometric contaction; TA: Tibialis anterior; MG: Medial gastrocnemius; VL: Vastuslateralis; MF: Multifidus; *: significant difference.

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Table 3: Measures of proprioception and nerve function before and after 8 weeks of intervention.

Variables	Intervention group (n=21)	Control group (n=17)	Time (T) effect η_p^2 (p-value)	Group (G) effect η_p^2 (p-value)	T×G interaction η_p^2 (p-value)
Proprioception (angle difference)					
Front					
Baseline	6.50±3.42	9.07±3.51	0.308 (<0.001)*	0.132 (0.027)*	0.132 (0.027)*
8th week	4.46±2.27	7.32±4.31			
Back					
Baseline	10.41±5.41	9.42±6.96	0.152 (0.016)*	0.003 (0.737)	0.122 (0.032)*
8th week	7.06±3.84	9.21±6.49			
Left					
Baseline	10.07±5.81	9.55±4.71	0.163 (0.012)*	0.044 (0.205)	0.165 (0.011)*
8th week	5.31±3.29	9.57±6.69			
Right					
Baseline	8.75±5.17	7.87±6.18	0.187 (0.007)*	0.01 (0.557)	0.099 (0.055)
8th week	4.60±2.81	7.10±5.24			
Nerve conduction studies					
PPeroneal nerve					
Latency (msec)					
Baseline	4.19±1.2	4.12±1.32	0.071 (0.105)	0.009 (0.579)	0.094 (0.061)
8th week	3.70±0.75	4.15±1.2			
Amplitude (mV)					
Baseline	4.44±2.21	4.45±1.85	0.097 (0.058)	0.012 (0.507)	0.094 (0.061)
8th week	4.44±2.05	4.34±1.67			
Duration (msec)					
Baseline	10.32±2.02	10.61±2.8	<0.001 (0.968)	0.016 (0.453)	0.041 (0.222)
8th week	10.06±2.03	10.86±2.4			
NCV (m/sec)					
Baseline	38.37±6.62	36.37±7.9	0.187 (0.007)*	0.049 (0.183)	0.137 (0.022)*
8th week	40.84±5.88	36.60±8.47			
Tibial nerve					
Latency (msec)					
Baseline	4.80±1.13	4.59±0.79	0.002 (0.803)	0.009 (0.574)	0.125 (0.03)*
8th week	4.39±0.92	4.91±0.94			
Amplitude (mV)					
Baseline	6.74±3.83	6.12±3.89	0.029 (0.311)	0.003 (0.758)	0.032 (0.279)
8th week	6.72±3.56	6.56±4.3			
Duration (msec)					
Baseline	8.04±1.34	7.92±2.02	0.023 (0.367)	0.001 (0.872)	0.025 (0.346)
8th week	8.03±1.71	8.33±2.03			
NCV (m/sec)					
Baseline	37.94±7.35	38.39±11.69	0.315 (<0.001)*	<0.001 (0.941)	0.013 (0.503)
8th week	42.67±8.57	41.78±10.8			

NCV: Nerve conduction velocity; *: significant difference.

Nasseri et al. [37]. Motor nerve conduction studies were carried out using RMS Salus 2C electromyography/NCV machine. For deep peroneal nerve, an active surface electrode was placed over the extensor digitorum brevis (EDB) muscle and the reference electrode was placed over the tendon of EDB. Distal stimulation was given at 7-8 cm from the active electrode between the extensor digitorum longus and extensor hallucis longus, and proximal stimulation was given just below the head of fibula. For tibial nerve, the active surface electrode was placed over abductor hallucis and the reference electrode was placed distally near metatarsal head. Distal stimulation was given at 9 cm from active electrode behind and proximal to medial malleolus, and proximal stimulation was given slightly laterally to the midline of popliteal fossa, along the flexor crease of the knee. Nerve conduction studies are considered to be the most accurate, reliable and sensitive measure for peripheral nerve functions [37].

Electromyographical assessment

Surface electromyography (EMG) was used to record muscle activity. Surface EMG electrodes were placed on the tibialis anterior, medial gastrocnemius, vastus latralis and multifidus of right limb. The disposable bipolar Ag/AgCl surface electrodes were placed according to the SENIAM recommendations [38]. The diameter of electrodes was 10 mm and the inter-electrode distance was 25 mm. The electrodes were attached to the skin after shaving and cleansing the area with alcohol swab.

Maximal voluntary contractions (MVC) were initially carried out for each muscle as follows: (a) Tibialis anterior: The subject was asked to lie supine with the left leg in full extension and foot restrained in mid-range dorsiflexion. The subject attempted to dorsiflex the ankle joint against manual resistance by the investigator, which was applied at mid-dorsum of the foot. (b) Medial gastrocnemius: In the same position, with foot restrained in mid-range plantar flexion, the ankle of left leg attempted plantar flexion. Resistance was provided at the plantar aspect of mid-foot region. (c) Vastus lateralis: The subject sat upright with knees flexed at 90°, with the ankle of the left leg restrained from extending, and attempted to extend the knee against resistance provided at just above the ankle joint anteriorly. (d) Multifidus: The subjects laid prone on a couch and extended their back against the resistance provided at scapula by the investigator. The lower legs were strapped. In total, three trials of MVC were performed for 5 seconds of isometric phase. The subjects were asked to ensure maximum effort throughout 5 seconds; if not, the MVC were repeated. Electromyographic data was collected for 4700-4800 ms after the holding position started. The mean of 3 trials was calculated for the analysis. Root mean square (RMS) value was used for normalization of the EMG activity during the experimental procedures.

The electromyographical data were collected through a custom software and hardware design [PL3508 Power Lab 8/35 Data Acquisition System with Lab Chart Pro (AD Instruments, Australia)] at a sampling frequency of 1000 Hz and band-pass filtered between 5 and 500Hz. The signals were analogue/digitally stored on a personal computer.

Subjects then performed the following tasks: (a) bilateral stance on unstable balance board with eyes open; (b) bilateral stance on unstable balance board with eyes closed;

and (c) treadmill walking at self-paced speed with hand supported. Balance assessment was performed for 12 seconds while treadmill walk was performed for 3 minutes. The timer was started once the subject had established their balance or reached their self-paced speed during walking. If the subject lost their balance during the task (moved their feet from the specific points), the trial was terminated and restarted when they were able to balance themselves for full 12 seconds. Muscle activity were expressed in percentage MVIC and used for the analysis.

Co-contraction index during postural task and walking was calculated by equation[39]; Co-contraction index = (lower EMG / higher EMG) × (lower EMG + higher EMG), where lower EMG is the level of activity in the less active muscle and higher EMG is the level of activity in the more active muscle represented in the normalized RMS value. This method provided an estimate of the relative activation of the pair of muscles as well as the magnitude of co-contraction.

Sample size calculation

The number of subjects was determined by G. Power 3.15. In a previous study, peroneal nerve conduction velocity (NCV) in DPN patients was 36.6±4.1 m/s compared with 42.8±4.1 m/s in healthy controls[8]. Allowing that DPN patients might improve mean conduction velocity from 36.6 m/s to 39.7 m/s, 18 patients were required considering two tailed, alpha level of 0.05 and power (1-beta) of 0.85 in each group. We assumed a standard deviation of 4.1 of the response variable. Total 44 subjects were shown to be necessary including hypothesized 20% drop out.

Statistical analysis

The normality of distribution of all variables was verified using Shapiro Wilk test, skewness and histogram. Non-parametric test was used for the measures that showed non-normal distribution. Demographic characteristics and baseline measures were compared using independent t-test or Mann Whitney U test. 2×2 mixed model ANOVA was used to find out main effect (group effect and time effect) and time × group interaction. If the baseline values showed a significant difference between the groups, then 2×2 mixed ANCOVA was applied taking pre-values as covariate. All statistical analyses were carried out using SPSS version 21. Statistical significance was indicated if $p \leq 0.05$ and confidence interval was set at 95%. Data are presented as mean±SD unless otherwise indicated.

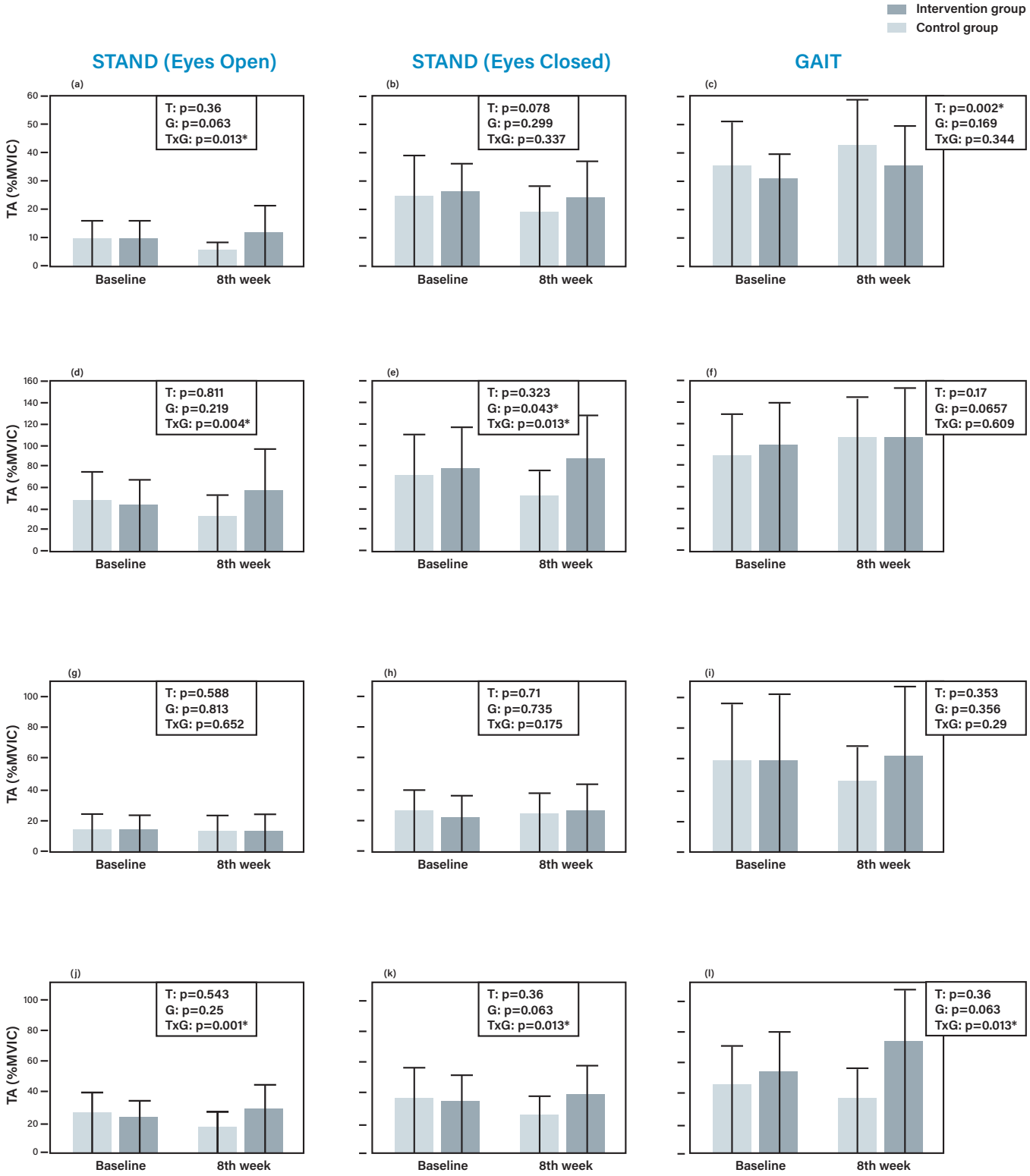
Results

Demographic characteristics have been presented in *Table 1*. Comparison of demographic characteristics revealed no significant difference between the groups except HbA1c ($p=0.017$). The between-group comparison of baseline assessments found significant difference only for proprioception in front direction ($p=0.029$) (*Table 2*).

Proprioception

Repeated measures ANOVA revealed a significant time effect for proprioception in all the four directions ($p \leq 0.016$), group effect was found significant only in the front direction ($p=0.002$) and time×group interaction was found significant for proprioception in front ($p=0.027$), back ($p=0.032$) and left ($p=0.011$) directions (*Table 3*). The intervention group in the present study showed more improvement in front, back, left and right direction (31.38%, 32.18%, 47.26%, and 47.42%, respectively) than control group (19.29%, 2.22%, 0.2%, and 8.89%, respectively).

Figure 2: EMG activity of Tibialis anterior (TA), medial gastrocnemius (MG), vastus lateralis (VL) and multifidus (MF) during different task before and after 8 weeks of intervention. *: significant difference.



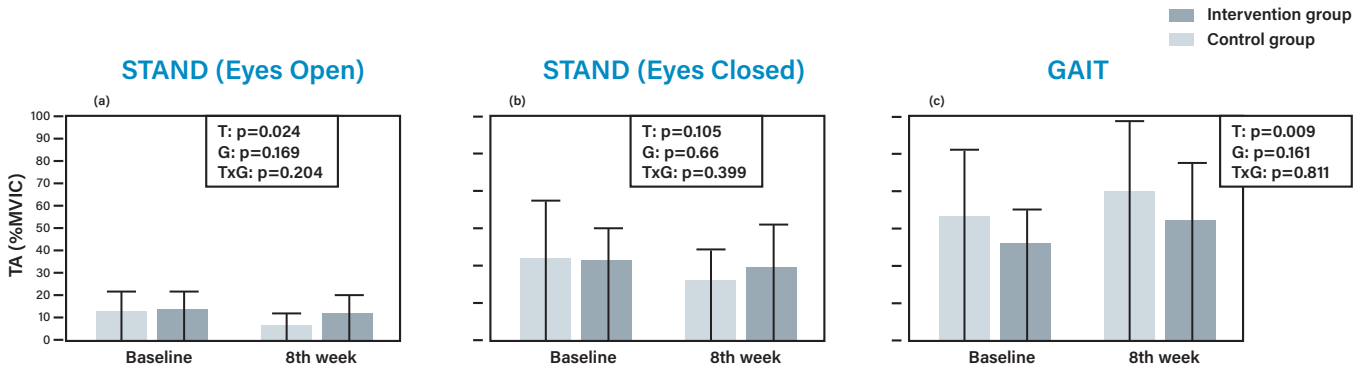


Figure 3: Co-contraction index of muscles during different task before and after 8 weeks of intervention. *: significant difference.

Nerve conduction studies

There was significant difference in the conduction velocity of the peroneal nerve for time effect (p=0.007) and time × group interaction (p=0.022) whereas a non-significant difference was found for the group effect (p>0.05). Conduction velocity of the peroneal nerve showed 6.43% increase in the intervention group whereas control group showed an increase of 0.6% only. Both within- and between-group comparisons of latency, amplitude and duration of the peroneal nerve were found to be non-significant (*Table 3*).

Conduction velocity for tibial nerve showed significant time effect (p<0.001) while group effect and time × group interaction were non-significant. There was an increase in conduction velocity in both groups (12.46% in the intervention group and 8.83% in the control group). Also, time × group interaction was found significant for tibial nerve latency (p=0.03). The intervention group showed decrease in the distal latency of tibial nerve by 8.54%, while the control group showed increase in the latency by 6.97%. There was no significant difference in the amplitude and duration of the peroneal nerve with respect to time or group (*Table 3*).

Electromyographic activity

Figures 2 and *3* present the results of EMG analysis of the muscles studied after intervention. During eyes-open stance, the time×group interaction in the muscle activity of the tibialis anterior (p=0.013), medial gastrocnemius (p=0.004) and multifidus (p=0.001) showed significant changes after the intervention, whereas only medial gastrocnemius (p=0.003) and multifidus (p=0.004) showed significant changes in eyes-closed condition after the intervention. On the other hand, treadmill walking found significant group effect (p=0.002) as well as time × group interaction (p=0.003) for multifidus muscle indicate 20.66% reduction were recorded in the intervention group, while 37.57% increase was recorded in the control group. Also, treadmill walking showed significant time effect (p=0.002) for the tibialis anterior muscle (22.8% increase in the intervention group and 14.34% increase in the control group).

Discussion

The effect of sensorimotor and gait training on proprioception, nerve function and electromyographic activity of lower limb muscles in DPN patients were evaluated in the present study.

Proprioception

The results of our study revealed that intervention group significantly improve proprioception in front, back, left and right (closed to significant) directions which was found similar with the previous studies. Song et al. reported that balance exercises improved trunk proprioception in older adults with diabetic neuropathy [25]. Tai chi exercise has also enhanced the ankle and knee proprioception in adult and older population [40-42].

The present study included balance exercises that increase the stimulation of mechanoreceptors present in muscle spindle, golgi tendon organs and joint capsule responsible for enhancing proprioception inputs from foot, ankle and trunk [43]. Training also includes different patterns of walking comprising of small repetitive ankle and knee movement which improves proprioception. Also, a gradual increase in the difficulty of sensorimotor and gait exercises leads to enhance proprioception, as learning effect is one of the facts, which contributes to the improvement in the lower limb proprioception.

Previous studies suggest that loss of proprioception results in balance impairment experience multiple falls in older people [44]. Improvement in the proprioception decreases the risk of falls in the older population [45]. Though, the present study does not directly measure risk of falls, it indicates that improved proprioception might decrease the risk of falls in patients with DPN, thus, supporting the above findings.

Nerve conduction studies

There are few studies investigating lower limb nerve conduction in patients with diabetic neuropathy. Previous studies reported an improvement in NCV after aerobic or aerobic plus resistance exercise in diabetic population with or without neuropathy [26-28,30] which was found similar with our study. Hung et al. has also showed an increase in the NCV of the tibial nerve and median nerves after Tai chi exercise[29]. Hung et al. recruited diabetic patients without overt sign and symptoms of diabetic neuropathy [29], whereas we included diabetic patients with neuropathy, longer duration of diabetes, and higher level of HbA1C. Studies showed that NCV of the peroneal nerve can predict neuropathy-related mortality [46,47]. Moreover, a decrease in the latency of the tibial nerve was also recorded in our study after the exercise intervention.

The changes in NCV suggest partial regeneration or restoration of motor nerve function. The possible mechanisms of nerve function restoration after eight weeks of intervention are increased endoneural blood flow, decrease nitric oxide and decreased oxidative stress. Exercise induced microvascular circulation via endothelium vasodilation which increases endoneural blood flow [48], improves the abnormal perfusion and facilitates oxygen delivery to the nerve [49] reverses the chronic hypoxia of the nerves. Exercise enhanced nerve perfusion through ATP sensitive K+ channels opening in diabetic neuropathy [50]. Decreased nitric oxide production might also be useful in preventing diabetes-induced polyol pathways that have a deleterious effect on Schwann cells and the endothelium, thereby restoring nerve function [51]. Increased antioxidant enzymes and decreased serum C-reactive protein after Tai chi exercises indicate reduction of risk of oxidative stress [52]. Training has been also shown to increase levels of Na/K ATPase activity in rat muscle

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cells [53]. It is therefore, speculated that exercise intervention in diabetic neuropathy could be related to improvement of Na/K ATPase activity.

Electromyographic activity

Results of our study shows reduction in the activity of tibialis anterior (41.64%), medial gastrocnemius (30.94%) and multifidus (31.07%) during eyes open and decrease in the activity of tibialis anterior (22.14% but not significant), medial gastrocnemius (30.9%) and multifidus (27.63%) during eyes closed stance on an unstable platform, suggesting enhanced postural control at the level of ankle and trunk after eight weeks of intervention. Loss or reduction of proprioception and somatosensory feedback from lower limbs leads to an increase in the activity of lower limb and trunk muscles during postural task [16]. Present study found an increase in somatosensory and proprioceptive inputs (as described) from foot, ankle and trunk after sensorimotor and gait exercises; hence it decreased the activity of muscles around the ankle and trunk. Song et al. found decrease in the trunk reposition errors in eyes-open and eyes-closed stance in stable surface and in eyes open on foam surface after eight week of exercise in diabetic neuropathy patients [25]. The present study comprised of different balance exercises like sit to stand, wobble board exercise, toe and heel raise exercise which might give beneficial effect on the trunk proprioception. Also, core stabilization program in the interventional group enhanced the sensory inputs from the

trunk muscles and activation characteristics of trunk musculature [54,55]. The patients gained better sensory feedback by enhancing sensory inputs which decreased over contraction of muscle (which is compensatory strategy to gain more stability) around the joint.

Our study shows that the intervention helped in increasing the activity of tibialis anterior (22.8% in the interventional group and 14.34% in the control group) and medial gastrocnemius (18.89% in the interventional group and 8.8% in the control group) during treadmill walking, although the difference between the groups was not found to be significant. Sartor et al. results was found similar to our study; improvement in the ankle dorsiflexion and eccentric control of forefoot contact, as a function of the tibialis anterior, and increased participation of hallux and toes, as a function of medial gastrocnemius during walking [32]. Therefore, we can say that the intervention helps in increasing shock absorption during the initial contact phase of gait as contributed by the tibialis anterior and increasing push off power during heel off phase as contributed by the gastrocnemius. Technically, the skewed distribution of the data might be the reason for the statistically non-significant result. Although inconsistent, a large number of patients showed improvement in muscle activation during walking in the intervention group in comparison with the control

group. However, the patients reported better balance during walking on treadmill after the intervention and clinically found less compensatory adaptive strategy used during walking in the patients with DPN.

Interestingly, our study found reduction in the activity of multifidus during treadmill walking following the sensorimotor and gait training. Sensory integration relayed lesser motor response, therefore, multifidus activity was reduced during treadmill walking. Also, treadmill walking was challenging for the patients with lesser ankle strategy; therefore, the trunk leaned forward for maintaining balance as a compensatory strategy, consequently overloading the multifidus. After intervention better sensory feedback from foot and ankle helps proper use of ankle strategy. Thus, improvement in activity of the muscles around the ankle might have led to lesser compensation by trunk musculature with more erect trunk position, and therefore, lesser activation of the multifidus was found.

Clinical implications

Sensorimotor and gait training has revealed positive effects on proprioception, nerve function and activity of lower limb musculature. These exercises are feasible, easy and used in the clinical setup in patients with DPN. Also, the exercises may be given as home exercise protocol for patients moderately affected with DPN, due to lesser risk, better safety and exercises not requiring much supervision. However, we would like to mention the adverse events when one patient complained about aggravated pain in the leg during set of exercise intervention and another patient had hypoglycemia in only single session. The participants were offered no financial compensation, although the high compliance rate (86.36%) observed in our study suggests that the patients were satisfied with this form of therapy. These exercises should be incorporated along with glycemic control interventions, as they play an effective role as a preventive strategy for long term complications in patients with diabetic neuropathy.

Limitations and future perspective

There were several limitations to the study, including its small sample size, considering the larger variability in the parameters of the electromyographic activity. Also subjects in the control group were not controlled with home exercises during this period. Subjects recruited for the study primarily suffered from mild to moderate level of neuropathy, while those with severe neuropathy were relatively less in number, this limits the generalizability of the results to the entire population with DPN. In future, efficacy of sensorimotor and gait training should be assessed in sensory nerve function, in patients with severe diabetic neuropathy and with increase duration of exercise to see the significant changes in the electromyographic activity of the lower limb muscles.

Conclusions

Specific progressive sensorimotor and gait training improves proprioception and nerve conduction velocity. Due to better proprioceptive feedback, these interventions provide beneficial changes in the activity of muscles around the ankle and multifidus during postural control and walking in patients with DPN. ■

Appendix 1: Michigan Neuropathy Screening Instrument.

History (To be completed by the person with diabetes)		
1. Are your legs and/or feet numb?	Yes	No
2. Do you ever have any burning pain in your legs and/or feet?	Yes	No
3. Are your feet too sensitive to touch?	Yes	No
4. Do you get muscle cramps in your legs and/or feet?	Yes	No
5. Do you ever have any prickling feelings in your legs and/or feet?	Yes	No
6. Does it hurt when bed covers touch your skin?	Yes	No
7. When you get into the tub or shower, are you able to tell the hot water from the cold water?	Yes	No
8. Have you ever had an open sore on your foot?	Yes	No
9. Has your doctor ever told you that you have diabetic neuropathy?	Yes	No
10. Do you feel weak all over most of the time?	Yes	No
11. Are your symptoms worse at night?	Yes	No
12. Do your legs hurt when you walk?	Yes	No
13. Are you able to sense your feet when you walk?	Yes	No
14. Is the skin on your feet so dry that it cracks open?	Yes	No
15. Have you ever had an amputation?	Yes	No

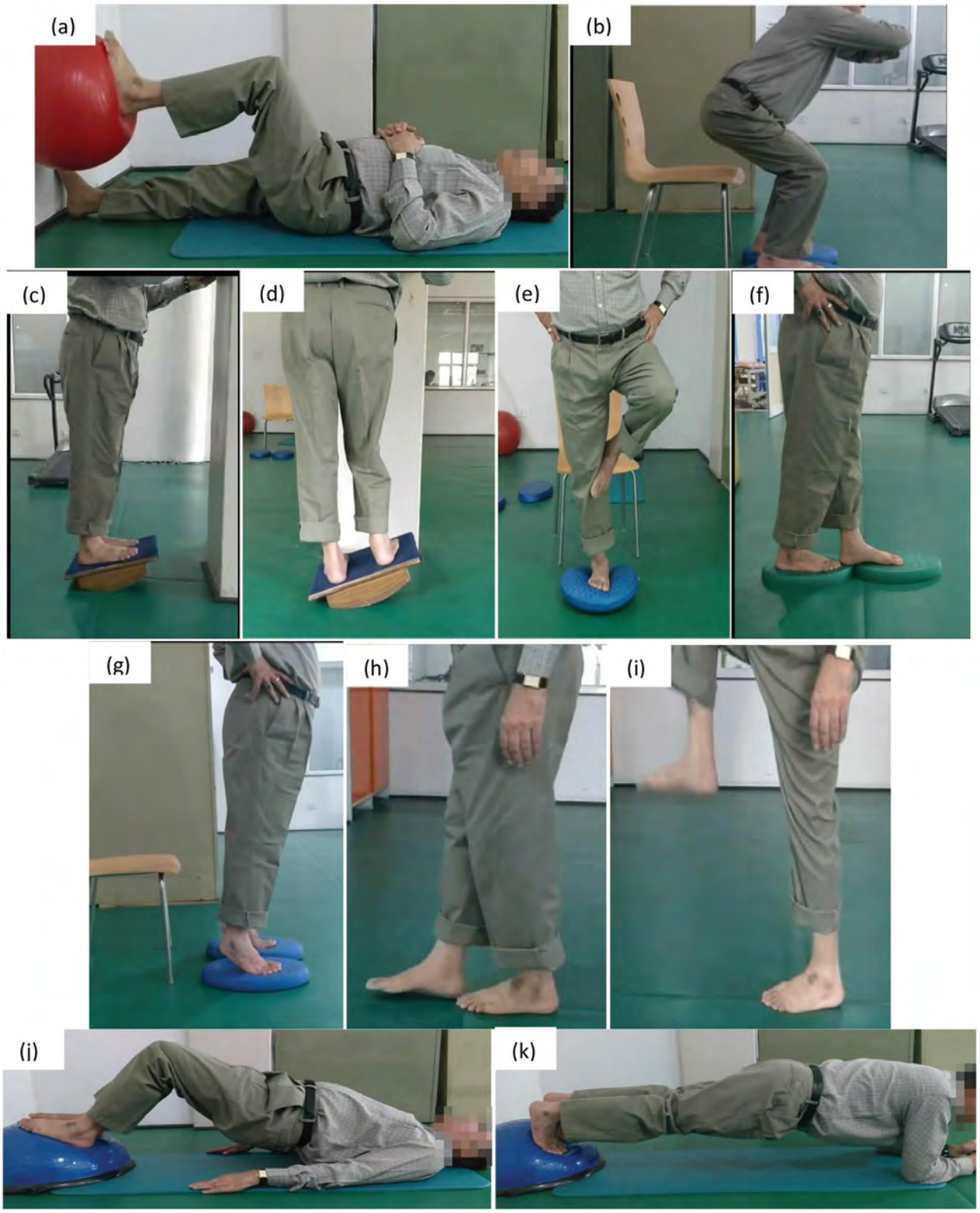
Physical Assessment	(To be completed by the health professional)					
1. Appearance of Feet						
	Right			**Left**		
	a. Normal	Yes	No	Normal	Yes	No
	b. If no, check all that apply:			b. If no, check all that apply:		
	Deformities			Deformities		
	Dry skin, callus			Dry skin, callus		
	Infection			Infection		
	Fissure			Fissure		
	Other			Other		
	Specify:_____			Specify:_____		
	Right			**Left**		
2. Ulceration	Absent	Present		Absent	Present	
3. Ankle reflexes	Present	Reinforcement	Absent	Present	Reinforcement	Absent
4. Vibration perception at great toe	Present	Decreased	Absent	Present	Decreased	Absent
5. Monofilament	Normal	Reduced	Absent	Normal	Reduced	Absent
Signature:				Total Score:		

Appendix 2: Description of sensorimotor and gait training program.

Exercises	Level 1	Level 2	Level 3	Level 4
Sensory training	Wall slides First 3 session: 20 reps Next 3 session: 20 reps × 2 sets	Wall slides First 3 session: 20 reps Next 3 session: 20 reps × 2 sets	Wall slides with red color gym ball First 3 session: 20 reps Next 3 session: 20 reps × 2 sets	Wall slides with red color gym ball First 3 session: 20 reps Next 3 session: 20 reps × 2 sets
Balance training (sensory component)	Bipedal wobble board exercise (bidirectional wobble board) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Bipedal wobble board exercise (multidirectional wobble board) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Unipedal wobble board exercise (bidirectional wobble board) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Unipedal wobble board exercise (multidirectional wobble board) First 3 session: 3mins Next 3 session: 3mins × 2 sets
	Unipedal stance (blue oval stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Unipedal stance (grey oval stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Unipedal stance (blue round stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Unipedal stance (silver round stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets
	Tandem Stance (blue oval stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Tandem Stance (grey oval stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Tandem Stance (blue round stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets	Tandem Stance (silver round stability trainer) First 3 session: 3mins Next 3 session: 3mins × 2 sets
Balance training(motor component)	Toe and Heel raise (blue oval stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Toe and Heel raise (grey oval stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Toe and Heel raise (blue round stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Toe and Heel raise (silver round stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets
	Sit to stance (blue oval stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Sit to stance (grey oval stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Sit to stance (blue round stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Sit to stance (silver round stability trainer) First 3 session: 10 reps Next 3 session: 10 reps × 2 sets
Core training	Normal back bridging First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Back bridging on bosu ball First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Back bridging on silver stability trainer First 3 session: 10 reps Next 3 session: 10 reps × 2 sets	Back bridging on gym ball First 3 session: 10 reps Next 3 session: 10 reps × 2 sets
	Prone bridging First 3 session: 5 reps Next 3 session: 5 reps × 2 sets	Prone bridging on bosu ball First 3 session: 5 reps Next 3 session: 5 reps × 2 sets	Prone bridging on silver stability trainer First 3 session: 5 reps Next 3 session: 5 reps × 2 sets	Prone bridging on gym ball First 3 session: 5 reps Next 3 session: 5 reps × 2 sets
Gait training	Normal walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	High march walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	Backward walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	High march backward walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets
	Walk on the line First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	Tandem walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	High march tandem walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets	High march tandem backward walk First 3 session: 5 mins Next 3 session: 5 mins× 2 sets

1 minute of rest between the sets; 1 minute to 3 minutes of rest between the two exercises.

Appendix 3: Sensorimotor and gait exercises. Sensorimotor exercises: (a) Wall slides with ball; (b) Sit to stand; (c) and (d) Bipedal wobble exercise; (e) Unipedal stance; (f) Tandem stance; (g) Toe and heel raise; Gait training: (h) Tandem walk (i) High march walk; Core training: (j) Back bridging on bosu ball (k) Prone bridging on bosu ball.



Ethics Approval

Ethical approval was taken from Institutional Ethics Committee, Jamia Millia Islamia, New Delhi, reference number: 17/9/40/JMI/IEC/2015, dated-16/11/2015.

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Footnotes

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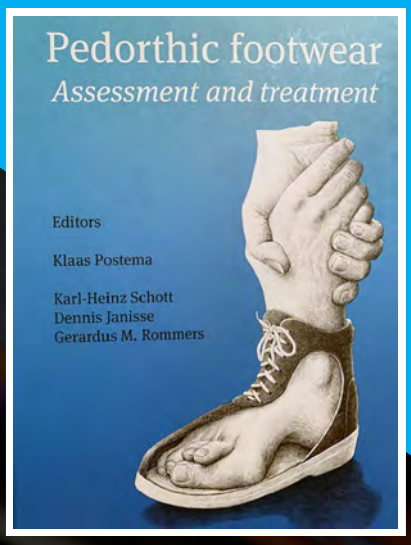

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Diabetic Foot Australia guideline on footwear for people with diabetes

Abstract

Background
The aim of this paper was to create an updated Australian guideline on footwear for people with diabetes.

Methods
We reviewed new footwear publications, (inter) national guidelines, and consensus expert opinion alongside the 2013 Australian footwear guideline to formulate updated recommendations.

Result
We recommend health professionals managing people with diabetes should:

(1) Advise people with diabetes to wear footwear that fits, protects and accommodates the shape of their feet.

(2) Advise people with diabetes to always wear socks within their footwear, in order to reduce shear and friction.

(3) Educate people with diabetes, their relatives and caregivers on the importance of wearing appropriate footwear to prevent foot ulceration.

(4) Instruct people with diabetes at intermediate- or high-risk of foot ulceration to obtain footwear from an appropriately trained professional to ensure it fits, protects and accommodates the shape of their feet.

(5) Motivate people with diabetes at intermediate- or high-risk of foot ulceration to wear their footwear at all times, both indoors and outdoors.

(6) Motivate people with diabetes at intermediate- or high-risk of foot ulceration (or their relatives

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and caregivers) to check their footwear, each time before wearing, to ensure that there are no foreign objects in, or penetrating, the footwear; and check their feet, each time their footwear is removed, to ensure there are no signs of abnormal pressure, trauma or ulceration.

(7) For people with a foot deformity or pre-ulcerative lesion, consider prescribing medical grade footwear, which may include custom-made in-shoe orthoses or insoles.

(8) For people with a healed plantar foot ulcer, prescribe medical grade footwear with custom-made in-shoe orthoses or insoles with a demonstrated plantar pressure relieving effect at high-risk areas.

(9) Review prescribed footwear every three months to ensure it still fits adequately, protects, and supports the foot.

(10) For people with a plantar diabetic foot ulcer, footwear is not specifically recommended for treatment; prescribe appropriate offloading devices to heal these ulcers.

Conclusions

This guideline contains 10 key recommendations to guide health professionals in selecting the most appropriate footwear to meet the specific foot risk needs of an individual with diabetes.

Background

Diabetic foot ulcers are a costly complication of diabetes, reducing people's quality of life, and increasing morbidity, mortality and healthcare expenditure [1-4]. The annual incidence of foot ulcers in people with diabetes is approximately 2%, both globally [3] and in Australia [5], and the lifetime risk is between 19% and 34% [6]. Additionally, diabetic foot ulcers are the leading cause of lower extremity amputations and cause approximately 2% of all hospitalizations [3-5, 7, 8]. Therefore, the prevention of diabetic foot ulcers is of paramount importance.

Diabetic foot ulcers are typically caused by repetitive stresses (shear and pressure) on the foot in the presence of the diabetes-related complications of peripheral neuropathy or peripheral artery disease, and their healing is often complicated by the development of infection [9-13]. Use of inappropriate footwear or walking barefoot typically increases the magnitude of the local mechanical repetitive stresses on the foot that are leading causes of the development of diabetic foot ulceration [9-12]. Thus, it is recommended that people with diabetes wear appropriate footwear designed to reduce repetitive stresses at all times, to help prevent diabetic foot ulceration [14, 15].

In 2013, the Australian Diabetes Foot Network published one of the first nationwide practical guidelines on the provision of footwear for people with diabetes [16]. Since this publication, pivotal new studies [9, 17-30] and international guidelines [10, 14, 15] have been published on footwear for people with diabetes. This new literature provides a stronger evidence-base for the effectiveness of footwear in ulcer prevention for people with diabetes, new data-driven directions for the prescription of footwear, and new evidence on the importance of adherence to wearing footwear [9, 10, 14, 15, 17-30]. The aim of this article is to update the 2013 Australian practical guideline [16], and thereby creating a new *Diabetic Foot Australia guideline on footwear for people with diabetes*.

Methods

Procedure for developing the guideline

The *Diabetic Foot Australia guideline on footwear for people with diabetes* aims to provide guidance to the multidisciplinary healthcare professionals involved in the provision of footwear for people with diabetes. The *Australian Diabetes Foot Network 2013 practical guideline on the provision of footwear* [16] was used as a baseline for the creation of this updated guideline. Information from the 2013 footwear guideline was updated first by the primary author after reviewing and incorporating any new footwear-related recommendations from the most recent Australian National Health and Medical Research Council (NHMRC) diabetic foot guideline [31] and the International Working Group on the Diabetic Foot (IWGDF) guidance documents [10, 14, 15]. The primary author then reviewed and incorporated common findings from all recent systematic reviews on footwear interventions for people with diabetes [17-22], recent randomized controlled trials included in these reviews [23, 24], and finally any further studies obtained from hand searching reference lists of these articles and an additional non-systematic search of the literature [9, 25-30]. After collating all findings, three tables and one figure were created describing footwear requirements and offloading effects of footwear modifications to prevent diabetic foot ulceration, based on published literature [10, 15, 16, 32-34] and expert opinion. Furthermore, to ensure a common and clear vocabulary between all the different multidisciplinary healthcare professionals involved in the provision of footwear for people with diabetes [14, 31], a table of definitions for common terms related to footwear for people with diabetes was developed based on literature [15, 16, 32, 33] and expert opinion (*Table 1*).

The first draft of this guideline was written by the first author (JvN), and then sent to two co-authors (PAL and PW) for critical review and expert opinion. A second draft incorporating consensus feedback from the three authors was sent to all authors for

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Table 1: List of definitions related to footwear for people with diabetes

Term	Definition
Abnormal foot shape	A foot shape that cannot be accommodated in pre-fabricated footwear. This includes, but is not limited to, feet with: hallux valgus, clawed/hammer toes, severe pes-planus or cavus foot type, abnormally wide feet, flat foot, minor amputation or Charcot foot.
Bespoke footwear	Synonym for "Custom-made medical grade footwear".
Custom-made footwear	Synonym for "Custom-made medical grade footwear".
Custom-made insole	An insole that is custom-made to the individual's foot using a 2D or 3D impression of the foot, and that is often built-up in a multi-layer construction. This may also incorporate other features, such as a metatarsal pad or metatarsal bar. The insole is designed to conform to the shape of the foot, providing cushioning and redistribution of plantar pressure.
Custom-made medical grade footwear	Footwear uniquely manufactured for one person, when this person cannot be safely accommodated in pre-fabricated medical grade footwear. It is made to accommodate deformity and relieve pressure over at-risk sites on the plantar and dorsal surfaces of the foot. In-depth assessment, multiple measurements, impressions or a mould, and a positive model of a person's foot and ankle are generally required for manufacture.
Customised insole	Term to denote a pre-fabricated insole to which minor modifications specific to a person's foot may have been made. This term is not synonymous with "Custom-made insole".
Depth-inlay footwear	Synonym for Extra-depth footwear.
Depth footwear	Synonym for Extra-depth footwear.
Extra-depth footwear	Footwear constructed with additional depth and volume in order to accommodate deformity such as claw/hammer toes and/or to allow for space for a thick insole. Usually a minimum of 5 mm (~3/16″) depth is added compared to pre-fabricated footwear. Even greater depth is sometimes provided in footwear that is referred to as double depth or super extra-depth.
Footwear modification	Modification to existing footwear with an intended therapeutic effect, e.g. pressure relief.
In-shoe orthosis/orthotic	Term used for device put inside the shoe to achieve pressure reduction or alteration in the function of the foot. Can be pre-fabricated or custom-made.
Liner	Synonym for insole.
Medical grade footwear	Footwear that meets the specific needs of a person. Can be either pre-fabricated (see "Pre-fabricated medical grade footwear") or custom-made (see "Custom-made medical grade footwear").
Metatarsal pad	Small pad placed proximal to the metatarsal head to relieve focal pressure and transfer load more proximally.
Metatarsal bar	Bar extending across part of or the entire forefoot placed proximal to the metatarsal heads to relieve focal pressures and transfer load more proximally.
Off-the-shelf footwear	Readily available footwear that has not been modified and has no intended therapeutic functions.
Orthopaedic footwear	Synonym for "Custom-made medical grade footwear".
Pedorthic footwear	Synonym for "Medical grade footwear". Can be either pre-fabricated (in that case synonym for "Pre-fabricated medical grade footwear") or custom-made (in that case synonym for "Custom-made medical grade footwear").
Pedorthic footwear modification	Synonym for "Footwear modification".
Pre-fabricated medical grade footwear	Pre-fabricated footwear that meets the specific needs of a person, on the basis of footwear that provides extra depth, multiple width fittings and features designed to accommodate a broader range of foot types. Other features may include modified soles, fastenings and smooth internal linings. This type of footwear is usually available at specialty shoe shops.
Pre-fabricated insole	An "off-the-shelf" flat or contoured insole made without reference to the shape of the patient's foot.
Shoe insert	Synonym for insole or in-shoe orthosis.
Shoe last	Last used to make footwear. The upper of the footwear is moulded or pulled over the last. The last shape defines the footwear shape including the outsole shape, heel pitch and toe spring. For off-the-shelf or pre-fabricated footwear generically generated lasts in different sizes are used.
Therapeutic footwear	Generic term for footwear that is designed to allow some form of treatment. May refer to both custom-made or pre-fabricated medical grade footwear.
Toe orthosis	Synonym for "In-shoe orthosis", but specifically for the toe.

Several healthcare disciplines may be involved in the provision of footwear for people with diabetes. Having a common vocabulary is essential for clear communication. We propose to use the following definitions, obtained from [15, 16, 32, 33] and authors' expert opinion.

critical review and expert opinion feedback. The authors of this guideline, all (inter)national experts in the field of diabetic foot ulcer and footwear management, came from the following backgrounds: podiatric medicine (n = 5), podiatric surgery (n = 1), human movement science (n = 2), wound medicine (n = 2), pedorthics (n = 1), rehabilitation medicine (n = 1), endocrinology (n = 1), and vascular surgery (n = 1). A third draft incorporating feedback from all co-authors was written by the first author (JvN) and again sent to all co-authors for review. This process was repeated one more time, until consensus was reached from all authors, leading to the final version of the guideline, approved by all authors.

Definitions for foot risk status

The purchase and wearing of appropriate footwear is an important process of care for all individuals with diabetes. This importance increases as the individual's risk for developing a foot ulcer increases. Different classifications for foot risk status are used worldwide. For the purpose of this Australian footwear guideline we followed the classification provided in the Australian NHMRC guideline [31]:

(i) Low-risk of foot ulceration: people with no identifiable risk factors on foot screening (no peripheral neuropathy, peripheral artery disease, foot deformity, previous foot ulcer, or history of lower-extremity amputation).

(ii) Intermediate-risk of foot ulceration: people with only one risk factor on foot screening (either peripheral neuropathy, peripheral artery disease or foot deformity) and no previous foot ulcer or amputation.

(iii) High-risk of foot ulceration: people with two or three risk factors on foot screening (peripheral neuropathy, peripheral artery disease or foot deformity) or with a previous foot ulcer or amputation.

According to the NHMRC guideline, Aboriginal and Torres Strait Islander people with diabetes are considered to be at high-risk for foot ulceration, until the person's level of risk is adequately assessed and confirmed otherwise [31].

To determine foot risk status, all people with diabetes should undergo at least a yearly foot screening by an appropriately trained registered healthcare professional with demonstrated competency [14, 31]. People with an intermediate- or high-risk foot status should be screened at least once every 3 to 6 months [14, 31]. In accordance with the NHMRC guideline, this should consist of screening for peripheral neuropathy (10 g monofilament sensitivity; vibration perception; neuropathy disability score), peripheral artery disease (palpation of peripheral pulses; ankle-brachial pressure index; toe-brachial pressure index), foot deformity (six point scale scoring small muscle wasting, Charcot foot deformity, bony prominence, prominent metatarsal head, hammer or claw toes and limited joint mobility), and assessment of a history of foot ulcer(s) or lower-extremity amputation [31]. The Australian Diabetes Society has published a video-example of such a foot examination (*Fig.1*) [35].

Structure of the guideline

This guideline consists of three parts and a discussion. Firstly, footwear recommendations and their rationale

Photo credit: Provided by the Authors

Figure 1: Promoting Optimal Diabetes Foot Care - The Foot Examination - Australian Diabetes Society (*click to play*) https://diabetessociety.com.au/diabetesfoot/the-foot-examination.asp.

are provided for people at-risk of foot ulceration; These recommendations apply to people at low-, intermediate- or high-risk. Secondly, additional specific footwear recommendations and their rationale are provided for people at intermediate- or high-risk of foot ulceration. Thirdly, footwear and offloading recommendations for people with a diabetic foot ulcer are summarised. Finally, considerations on footwear provision, on education and adherence, on cultural and geographical differences, and on methodology and terminology are discussed.

Results

This guideline contains 10 key recommendations to guide health professionals managing people with diabetes choosing the most appropriate footwear for the person's specific foot risk needs (*Table 2*). The recommendations and their rationale are described separately in this section.

Footwear for people with diabetes at-risk of foot ulceration

Recommendation 1:

Advise people with diabetes to wear footwear that fits, protects and accommodates the shape of their feet.

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People with diabetes should wear footwear that fits, protects and accommodates the shape of their feet [14] (see *Table 3* and *Fig. 1*). This includes having adequate length, width,

Table 2: Recommendations on footwear for people with diabetes

#	Recommendations
For all people at-risk of foot ulceration	
1	Advise people with diabetes to wear footwear that fits, protects and accommodates the shape of their feet
2	Advise people with diabetes to always wear socks within their footwear, in order to reduce shear and friction
3	Educate people with diabetes, their relatives and caregivers on the importance of wearing appropriate footwear to prevent foot ulceration
For people at intermediate- or high-risk of foot ulceration	
4	Instruct people with diabetes at intermediate-or high-risk of foot ulceration to obtain footwear from an appropriately trained professional to ensure it fits, protects and accommodates the shape of their feet
5	Motivate people with diabetes at intermediate- or high-risk of foot ulceration to wear their footwear at all times, both indoors and outdoors
6	Motivate people with diabetes at intermediate- or high-risk of foot ulceration (or their relatives and caregivers) to check their: a. footwear, each time before wearing, to ensure that there are no foreign objects in the footwear, or penetrating, the soles b. feet, each time their footwear is removed, to ensure that there are no signs of abnormal pressure, trauma or ulceration
7	For people with a foot deformity or pre-ulcerative lesion, consider prescribing medical grade footwear, which may include custom-made in-shoe orthoses or insoles
8	For people with a healed plantar foot ulcer, prescribe medical grade footwear with custom-made in-shoe orthoses or insoles with a demonstrated plantar pressure reducing effect at the high-risk areas
9	Review prescribed footwear every three months to ensure it still fits, protects, and supports the foot
For people with diabetic foot ulceration	
10	For people with a plantar diabetic foot ulcer, footwear is not specifically recommended for treatment; prescribe appropriate offloading devices to heal these ulcers

and depth (and consequently adequate girth, i.e. adequate volume) [10, 15, 16, 32, 33]. A particular emphasis may need to be placed on the toe box of the shoe that should be consistent with the shape of the forefoot and toes of the person. An enclosed heel with a stabilising heel counter is recommended. Open-heel footwear can result in direct trauma injury to the heel and may require a person to claw their toes in order to keep the footwear fixed to their feet, further increasing the repetitive stress under their forefoot, and in turn the risk of ulceration. Adequate closure of the footwear is needed, to prevent the foot from sliding forwards and thus causing shear injury to the toes or plantar foot [36]. All features in *Table 3* should be considered in combination, as their intended function is closely related and changes to one feature may affect other features and overall function [10, 15, 16, 32, 33].

People at low-risk of foot ulceration can usually be safely accommodated in a wide range of off-the-shelf footwear without specific requirements, provided the footwear is correctly fitted and appropriate for the activity to be undertaken [10, 15, 16, 32, 33]. For people at intermediate- or high-risk of foot ulceration, see recommendations 4-9. When new footwear is provided to a person with diabetes at low-risk of foot ulceration, advise them that a "wear-in" period may be needed where they slowly increase the number of hours per day the footwear is used, and that

Table 3: Requirements for footwear for people with diabetes

Feature	Requirements
Length	Inner length of the footwear should be 1–2 cm longer than the foot length as measured from heel to the longest toe when a person is standing. Adequate length needs to be confirmed when people are weight-bearing while wearing the footwear.
Depth	Depth should accommodate the toes to move freely without causing pressure at either the medial, lateral or the dorsal side.
Width	Width should equal the width of all parts of the foot. Width is good when the upper can be slightly bunched. The relation between forefoot and hindfoot is important, as accommodating a wide forefoot may result in the heel being too wide.
Height	Footwear height can be low, ankle-high, or high. High footwear provides more firmness, stability and reduces joint motion. The shaft of high footwear also contributes to forefoot pressure reduction. See further Table Table33 for specific height requirements for people with a foot deformity.
Insole	The removable moulded insole can be pre-fabricated, adjusted or custom-made. The primary function of the insole is pressure redistribution. This is achieved via the principle of increasing the contact area between the foot and the insole, and the addition of corrective elements in the insole. Shock-absorbing, soft but sufficiently resilient and non-slippery materials should be used. See further Table Table44 for the offloading effects of specific insole modifications.
Outsole	Rubber, plastic, and leather can all be used in construction of footwear outsoles, but rubber outsoles are thought to be superior. Outsoles can be supple, toughened or stiff. The shoe should not be more supple than the foot, or friction between foot and shoe will develop during push-off. See further Table Table33 for specific outsole requirements for people with a foot deformity and Table Table44 for the offloading effects of specific modifications.
Rocker profile	Rocker profiles have proven effectiveness in reducing plantar pressures, especially the forefoot. The rocker profile chosen depends on the affected joints and is determined by the apex position (pivot point) and the angle from the pivot point to the tip of the toe. For plantar pressure reduction of the metatarsophalangeal joints, the pivot point needs to be proximal to these joints. The rocker profile also impacts balance; the more proximally placed, the greater the balance disturbance. A person's balance should therefore always be taken into account when deciding on the rocker profile.
Heel enclosure	An adequately fitting and enclosed heel is recommended, as open backed footwear or a heel enclosure that is too wide can result in injury and usually requires a person to claw their toes in order to keep them on. The heel counter needs to be free of edges protruding into the footwear.
Heel lift	The heel lift (or heel-forefoot difference, or pitch) should be generally 1.5–2 cm, and should not exceed 3 cm.
Closure	Adequate closure (or fixation) is needed to keep the foot from sliding forward. Closure should allow secure longer-term fastening and individual adjustment. Laces have long been considered the optimal choice; however, alternatives that are easier to use while still meeting these criteria are available as well, and innovative closures continue to be developed.
Uppers	The uppers consist of the 'quarter'(hind- and midfoot) and 'vamp' (forefoot and toes). Uppers should be made from leather or a combination of materials (similar to sports shoes), with smooth inner lining made from a material that does not harden over time, with limited seams and preferably no seams in the vamp area as they reduce the ability of the leather to give. Uppers should be breathable and durable and have the ability to mould to deformities of the foot without resulting in pressure areas. Uppers can be supple, toughened or stiff. The vamp area should generally remain supple to accommodate the toes. See further Table Table33 for specific requirements for the uppers (quarter) for people with a foot deformity.
Toe box	The part of the shoe that covers and protects the toes. This should be supple (unless specific requirements (e.g. for building professionals) require otherwise), and should accommodate the shape of the toes, to avoid any rubbing on the toes.

Features and requirements in this table are based on [10, 15, 16, 32, 33] and authors' expert opinion; features are depicted in Fig.11.

they should be extra vigilant of their foot health in this period.

Recommendation 2:

Advise people with diabetes to always wear socks within their footwear, in order to reduce shear and friction.

Rationale

People with diabetes should be advised to always wear socks within their footwear, to reduce shear and friction. Further, advise people with diabetes to wear socks made of mostly natural materials (to prevent undue moisture accumulation), that are seamless (to prevent undue repetitive stresses) and do not have elasticated cuffs (to prevent undue oedema).

Recommendation 3:

Educate people with diabetes, their relatives and caregivers on the importance of wearing appropriate footwear to prevent foot ulceration.

Rationale

People with diabetes, their relatives and caregivers should also be educated on the importance of appropriate footwear to prevent foot ulceration, and the importance of adherence to wearing it [14]. Also, the importance of annual foot screens to assess their risk of foot ulceration, and to return for further footwear advice if their foot risk status increases should be emphasized [14].

Footwear for people with diabetes at intermediate- or high-risk of foot ulceration

Recommendation 4:

Instruct people with diabetes at intermediate- or high-risk of foot ulceration to obtain footwear from an appropriately trained professional to ensure it fits, protects and accommodates the shape of their feet.

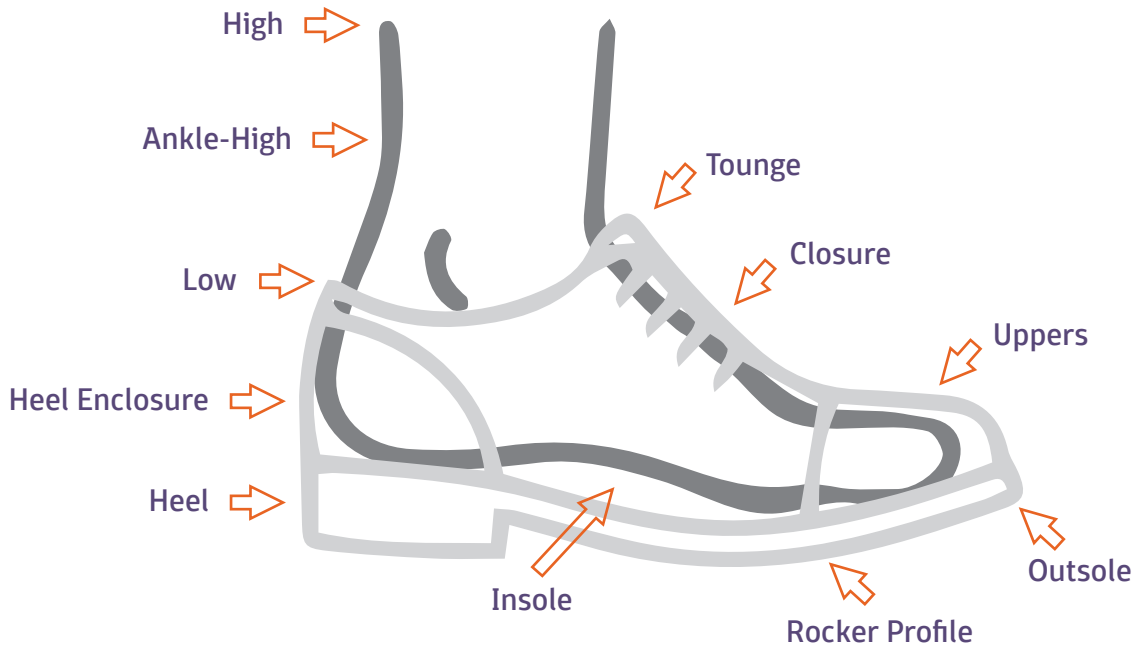

Figure 2: Footwear features. See *Table 2* for a description of the requirements of these features

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Rationale

People with only one risk factor identified after foot screening (either peripheral neuropathy, peripheral artery disease, or foot deformity) are at intermediate-risk of foot ulceration, whereas people with two or three risk factors (peripheral neuropathy, peripheral artery disease or foot deformity) or with a previous foot ulcer or amputation are at high-risk of foot ulceration.

People who develop diabetic peripheral neuropathy lose protective sensation and their ability to feel pressure and pain. Thus, they may have a tendency to purchase poorly fitting footwear in an attempt to stimulate some sensory feedback [16, 37]. They also do not feel abnormally high repetitive stress (pressure or shear) caused by inappropriate footwear or walking barefoot and are more likely to develop pre-ulcerative lesions (e.g. callus or blisters) that subsequently lead to ulceration [9, 12]. People with peripheral artery disease are less likely to heal pre-ulcerative lesions or minor trauma due to inadequate perfusion, and as such need to avoid inappropriate footwear that may cause these situations. A foot deformity changes foot biomechanics and may lead to abnormally high repetitive stresses; high plantar pressure in particular increases the risk of foot ulceration and therefore needs to be accommodated. People with a previous foot ulcer are at high-risk of developing a new ulcer, with reported re-ulceration rates of 40-50% within the first 12 months after healing [6, 38]. Due to the high re-ulceration rates it is recommended that the term 'diabetic foot remission' is used with patients whose ulcer has healed, to highlight the need for ongoing vigilance to prevent ulcer recurrence [6, 39-41].

> "...people with diabetes should be instructed to obtain foorwear from an appropriately trained professional with demonstrated competencies..."

All people at intermediate- or high-risk of foot ulceration should be instructed to wear footwear that fits, protects and accommodates the shape of their foot (*Table 3* and *Fig. 2*). Due to the complexities in accommodating the foot and the importance of preventing foot ulceration, people with diabetes should be instructed to obtain their footwear from an appropriately trained professional with demonstrated competencies in footwear fitting for this population, to ensure the footwear meets all requirements.

Recommendation 5:

Motivate people with diabetes at intermediate- or high-risk of foot ulceration to wear their footwear at all times, both indoors and outdoors.

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Because of their increased risk, people with diabetes at intermediate- or high-risk of foot ulceration should be motivated to wear

their footwear at all times, both indoors and outdoors. When doing so, be aware that adherence to wearing footwear is significantly lower indoors compared to outdoors [30], while the majority of steps in these patient groups have been shown to be taken indoors [30, 42]. Depending on cultural preference, prescribing suitable footwear for outdoors and a second pair for indoors may be advisable. The indoor footwear should meet the same requirements with regard to adequacy of fit and offloading, but compromises might be made in the materials used in manufacture, as it is likely to experience less "wear-and-tear" compared to footwear used outdoor. See further the considerations on education and adherence.

Recommendation 6:

Motivate people with diabetes at intermediate- or high-risk of foot ulceration (or their relatives and caregivers) to check their:
a) footwear, each time before wearing, to ensure that there are no foreign objects in the footwear or penetrating the soles.
b) feet, each time their footwear is removed, to ensure that there are no signs of abnormal pressure, trauma or ulceration.

Rationale

People with peripheral neuropathy have lost the ability to feel pressure, pain or foreign objects. They, or their relatives and caregivers, need to be motivated to check their footwear each time before they are put on, to ensure that there are no foreign objects in the footwear or penetrating the soles. Furthermore, they should also check their feet each time their footwear is removed, to ensure that there are no signs of abnormal pressure, shear, trauma or ulceration. People should be advised to immediately seek help from an appropriately trained professional when their footwear is damaged or when signs of abnormal pressure, shear, trauma or ulceration on their feet are found.

Table 4: Specific footwear requirements for people with diabetes and a foot deformity

	Height	Outsole	Uppers (quarter)[b]	Tongue
Limited joint mobility	Low[a]	Toughened	Supple	Supple
Pes cavus	Ankle-high	Toughened	Toughened	Toughened[c]
Flexible flat foot with hallux valgus	High	Toughened	Toughened	Toughened[c]
Rigid flat foot with hallux valgus	Ankle-high	Toughened	Strong medial support	Toughened[c]
Charcot foot	High	Stiff	Toughened	Toughened[c]
Hallux or toe amputation	High	Stiff	Toughened	Toughened[c]
Forefoot amputation	High	Stiff	Stiff	Stiff

This table is based on [33].
[a]Unless a person has limited joint mobility in the ankle joint, in that case use ankle-high or high footwear.
[b]The uppers consist of quarter and vamp, the requirements here concern the quarters, as the vamp typically needs to remain supple to accommodate the toes (see further *Table 2*).
[c]When a tongue is toughened, it should be padded as well.

Recommendation 7:

For people with a foot deformity or pre-ulcerative lesion, consider prescribing medical grade footwear, which may include custom-made in-shoe orthoses or insoles.

Rationale

When a foot deformity, pre-ulcerative lesion is present, off-the-shelf footwear is not likely to be appropriate. Prescribing medical grade footwear (pre-fabricated or custom-made; *Table 1*) needs to be considered, to accommodate the altered biomechanics. This medical-grade footwear may also include custom-made in-shoe orthoses or insoles. Depending on the foot deformity present or the location of the pre-ulcerative lesion, the footwear requirements algorithms for prescription (*Table 4*) and footwear modifications (*Table 5*) should be followed [25, 33]. The outsole, uppers and tongue can be "supple", "toughened", and "stiff" [33]. Toughened or stiff features facilitate the even distribution of forces exerted on the foot; unfortunately, no measurable definition of these is available [33].

Recommendation 8:

For people with a healed plantar foot ulcer, prescribe medical grade footwear with custom-made in-shoe orthoses or insoles with a demonstrated plantar pressure relieving effect at the high-risk areas.

Rationale

For people with a healed plantar foot ulcer, off-the-shelf footwear is most unlikely to be sufficient. Medical grade footwear (pre-fabricated or custom-made; *Table 1*) with a demonstrated plantar pressure reducing effect at high-risk areas, including the previous ulcer location, needs to be prescribed. This medical-grade footwear should also include prescribed custom-made in-shoe orthoses or insoles to increase the plantar pressure reducing effect. Based on two recent randomised controlled trials, a 'demonstrated plantar pressure reducing effect' (combined effect of the new medical grade footwear with orthosis or insole) is defined as a › 30% reduction at the area of the highest plantar pressure in comparison to the same area in the patient's current footwear, or a level below 200 kPa if measured with a validated and calibrated system with a sensor area of 1 cm2 [23, 24]. When such footwear is being worn by patients, the risk of re-ulceration is smaller [23]. Again depending on the location of the previous ulcer and presence (or absence) of a foot deformity and high-risk areas, follow the footwear requirements algorithms for prescription (*Table 4*) and footwear modifications (*Table 5*), with additional options provided by orthoses [25, 33]. The recommendation of prescribing footwear with a demonstrated plantar pressure reducing effect is in line with strong recommendations from the IWGDF guidelines [15], but has yet to be implemented widely in clinical practice in Australia. Different systems with different validity and reliability are available to quantify in-shoe plantar pressure [43]. We encourage services to invest in regular plantar pressure measurement protocols in daily clinical practice for people with diabetes and a healed plantar foot ulcer, and implementing the algorithms outlined in *Tables 4* and *5*.

Recommendation 9:

Review prescribed footwear every three

Table 5: Plantar pressure reducing offloading effects of insole and footwear modifications

Region of Interest	Hallux	Toes 2-3	Toes 4-5	MTH 1	MTH 2-3	MTH 4-5	Midfoot medium	Midfoot lateral
Accommodative Insole Modifications								
1. Replacement of top cover[b]								
2. Local removal of material								
3. Local cushioning								
Corrective Insole Modifications								
4. Addition of metatarsal pad								
5. Addition of a trans-metatarsal bar								
6. Repositioning or metatarsal pad or bar								
7. Addition of medial arch support								
8. Adjustment of pivot point of insole								
Outsole modificattion								
9. Adjustment of pivot point of outsole								
Combined midifications								
1+2								
1+3								
1+4								
1+5								
1+6								

Legend:	>20% pressure reduction[a]	10-20% pressure reduction[a]	0-10% pressure reduction[a]

Med. medial, Lat. lateral. This table is based on [25].
For the blank cells in the matrix, there is either not enough information available, or pressure reduction was not statistically significant, or pressure increased; these modifications are therefore not recommended for these regions of interest.
[a]Pressure reduction was significantly different from 0 (p-values < .05).
[b]Replacement with a new top cover of the same material.

months to ensure it still fits, protects, and supports the foot.

Rationale

Both the foot and the footwear change shape over time. Prescribed footwear, and custom-made orthoses or insoles, should be reviewed every three months to ensure it still fits, protects and supports the foot. This three-month interval is recommended based on the randomised controlled trial by Bus and colleagues, who used a three-month interval to ensure prescribed footwear remained appropriate, on expert opinion from seeing wear and tear in footwear in daily clinical practice, and aligns with the regular foot-screening interval for people at intermediate- or high-risk of foot ulceration as recommended in the NHMRC guideline [23, 31]. For people with a healed plantar foot ulcer who have been prescribed medical grade footwear with a demonstrated plantar pressure relieving effect, this effect still needs to be present for the footwear to be considered appropriate. Based on the findings from the trial by Bus and colleagues [23], ongoing research into its implementation in daily clinical practice and expert opinion, we suggest a three- to six-month interval for reviewing and demonstrating the plantar pressure relieving effect with validated equipment.

Footwear for people with diabetic foot ulceration

Recommendation 10:

For people with a plantar diabetic foot ulcer, footwear is not specifically recommended for treatment; prescribe appropriate offloading devices to heal these ulcers.

Rationale

Footwear is not specifically recommended to treat a plantar diabetic foot ulcer in the IWGDF guidelines; in contrast offloading devices are recommended and necessary to heal these ulcers [15, 31]. We strongly recommend that any health professional treating a patient with a plantar diabetic foot ulcer ensures their patient has an appropriate offloading device. The most strongly recommended devices in the NHMRC guideline and IWGDF guidance documents are non-removable knee-high devices, such as a total contact cast or removable cast walker made irremovable [15, 31]. Only when knee-high devices are contraindicated or not tolerated by people with a diabetic foot ulcer should other offloading devices (such as forefoot offloading shoes and cast shoes), and lastly custom-made temporary footwear be considered [15].

Footwear for the unaffected foot of a person with a diabetic foot ulcer should follow the recommendations and criteria applied to people at high-risk of foot ulceration. Additionally, any height-difference caused by an offloading device may need to be corrected by adjusting the footwear of the unaffected leg. This can be achieved with internal footwear modifications or with external devices that are applied to the bottom of the shoe of the unaffected leg.

Prescribed footwear is needed once the ulcer is healed, again following the recommendations for people at high-risk of ulceration. When prescribed footwear cannot be made available immediately when the ulcer has healed, continuation in the offloading device meeting the offloading requirements

is needed until the prescribed footwear becomes available (see further details under 'considerations on footwear provision').

Discussion

This new 2017 Diabetic Foot Australia footwear guideline has updated the 2013 Australian footwear guideline to reflect the best available evidence from contemporary studies investigating footwear interventions, international guidelines and expert opinion. We have formulated 10 key recommendations to guide health professionals in selecting the most appropriate footwear to meet the specific foot risk needs of an individual with diabetes (*Table 2*), and provided the rationale behind these recommendations. In this discussion, we will add considerations on footwear provision, education and adherence, cultural and geographical differences, and methodology and terminology related to this guideline. These consideration provide further background with the recommendations, and discuss aspects relevant for implementation of the recommendations in daily clinical practice.

Considerations of footwear provisions

When providing footwear to a person with diabetes, ensure they know their foot risk status and confirm this via an evidence-based screening by an appropriately trained healthcare professional [31]. In addition to the foot screening, other factors that should be considered include the person's gait pattern, activity levels, occupation, level of mobility, living situation, cultural beliefs, personal goals, and preferences. These factors may influence the possible options for appropriate footwear.

When providing footwear, measure the length, width, depth and girth of the foot the footwear needs to accommodate and ensure that the footwear follows the criteria in *Tables 3* and *4*. For length and width, we suggest at a minimum using a Brannock measuring device [44]. Although new scanning devices are becoming available to measure foot shape, we still suggest depth requires clinical assessment until accuracy of these devices can be independently quantified, taking into account that people with peripheral neuropathy cannot feel whether depth is accurate. Evaluate the shoe fit with the person in standing position, preferably at the end of the day to ensure that any developing oedema is taken into account. Further considerations in relation to oedema are footwear height (high footwear may have a compression function), outdoor temperature, and changes in oedema treatment.

The timing of footwear provision is important for any footwear that is not pre-fabricated. This becomes even more important when a person with diabetes at intermediate- or high-risk does not have appropriate footwear at a given moment. The longer a person needs to wait to receive appropriate footwear, the more steps they will take in inappropriate footwear, potentially increasing the repetitive stresses on the foot and in turn the risk for foot ulceration. Timing is most important for people with a recently healed plantar foot ulcer. Delivery of their prescribed footwear should be coordinated to a point as close to healing as possible. Ideally, the transition from an offloading device required to heal the ulcer to the preventative footwear is immediate. Any delay in this transition increases the risk of ulcer recurrence. When appropriate preventative footwear is not available for a person with a nearly healed foot ulcer, footwear prescription should be initiated before the ulcer is healed. Prescription can be initiated when foot shape (especially volume), structure and function are not expected to change during the healing process, and should take the manufacturing time-schedule into account. When prescribed footwear cannot be made available immediately when the ulcer has healed, continuation in the offloading device meeting the offloading requirements is needed until the prescribed footwear becomes available. Further, when new footwear is provided to a person with diabetes after healing a foot ulcer, advise them that a "wear-in" period may be needed where they alternate the new footwear with the offloading device that was required to heal the ulcer, and that they should be extra vigilant with checking of their foot health in this period.

In Australia, various state-based schemes are available that may provide financial assistance to people with diabetes who require medical-grade footwear. However, these schemes change over time and discussion of the specific schemes is outside the scope of this guideline.

Considerations on education and adherence to wearing footwear

Early education on the importance of adequate footwear for foot health is important for all people with diabetes. This education needs to continue life-long, and needs to be expanded if a person's

level of risk of foot ulceration increases. The importance of footwear for people with diabetes should be discussed in the context of the individual's foot risk status and health literacy [45]. Education should aim to increase people's understanding of the requirements of their footwear to adequately fit, protect and accommodate their feet. This may also include, but is not limited to, education on proper donning of the footwear, the importance of wearing socks in footwear to reduce shear and friction, and explaining the risks to foot health of inappropriate footwear such as slippers and sandals, of narrow heels, of heels higher than 3 cm, and of pointy, flat or hard toe boxes. Education should further focus on motivating people with diabetes at intermediate- or high-risk of foot ulceration to wear their footwear at all times. Footwear can only be effective when it is worn, and adherence to wearing footwear is an important factor in foot ulcer prevention [17, 23, 26, 30].

Achieving better adherence is a challenge, and unfortunately we found no intervention studies on the effect of interventions that aim to increase footwear adherence in people with diabetes [17, 41]. However, we found a number of observational studies investigating reasons for (non-)adherence to footwear [26, 28, 45-49]. An improvement in walking has been described as the most important footwear-related characteristic affecting adherence, while the importance of cosmetic appearance and ease of use varies greatly between people [28, 48]. Rather than focusing on footwear characteristics, it is suggested in various studies that personal perceptions, values and experiences are more important factors to improve adherence [26, 28, 45-49]. A perceived benefit of footwear is associated with increased adherence to wearing the footwear [26], and conversely, a lack of understanding of the need for footwear hinders adherence [28]. Acceptance of the need for footwear is another important factor affecting adherence [28, 46, 47]. This does not only concern accepting the need for footwear, but also acceptance of the person's underlying diabetic foot disease [28, 46, 47]. Footwear has been described as a "visible representation of the disease", and people with diabetes at-risk of foot ulceration may choose to moderate their adherence to align with functional requirements and societal norms [28, 46, 47].

"Footwear is very personal and multiple other factors may need to be taken into account when providing footwear to a person with diabetes and ensuring this footwear is being used."

These personal values and experiences cannot be assessed using a standardized measurement device. Adequate communication between healthcare professionals and patients is needed to assess these perceptions [45, 50]. For this communication to be effective, it should be person-centred, not footwear-centred [45, 50]. Footwear is very personal, and this should be taken into account during

education and communication to ensure maximum acceptance of and adherence with the footwear provided [28, 47, 50].

For people at intermediate- or high-risk of foot ulceration, the importance of adherence to wearing appropriate footwear both indoors and outdoors needs extra attention. People at risk of foot ulceration have been found to perform the majority of their total daily steps indoors [30, 42], while their adherence to wearing their footwear is significantly lower indoors compared to outdoors [30]. To improve adherence, people may need to be made aware of the greater repetitive stresses on their feet when at home resulting from the greater number of steps. It has also been suggested to provide separate footwear for indoor and outdoor use [30]. For people from cultures that may prefer not to wear 'normal' footwear indoors, it is suggested that health professionals consider providing indoor footwear that is manufactured to not look like 'normal' footwear, which may then be more acceptable to be worn indoors.

"This means that to provide people with diabetes with appropriate footwear, their foot risk status must be assessed first."

Considerations on cultural and geographical differences

In this guideline, we describe features and criteria for footwear for people with diabetes, and specific recommendations based on a person's foot ulcer risk following the NHMRC risk classification. Footwear is very personal and multiple other factors may need to be taken into account when providing footwear to a person with diabetes and ensuring this footwear is being used. We acknowledge the cultural differences in regard to footwear behaviour, specifically for Aboriginal and Torres Strait Islander people and from other diverse ethnic backgrounds. Furthermore, individuals in geographically rural and remote areas of Australia may have a limited range of footwear options available to them, and limited access to appropriately trained professionals. However, we decided not to provide specific recommendations for different cultures or for people living in rural and remote areas. The criteria and recommendations in this guideline are to be seen as the standards to be achieved, and these recommendations can be used by clinicians in their communications to discuss the footwear requirements for each person's situation. Specific circumstances may require that a compromise is made to the recommendations, which then may be considered to be better than no footwear at all. However, in our opinion, offering deviations from the standards in this guideline, without supporting evidence and solely based on specific cultural or geographical backgrounds of people, does not align with offering equality of best practice care for all people and may increase the risk of foot ulceration and will weaken this guideline. Rather, we encourage healthcare professionals

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to use this guideline to discuss footwear requirements with people with diabetes, to try and achieve, if needed, a compromise that is optimal for the person's situation that most closely aligns with the requirements and recommendations described in this guideline.

Considerations on methodology and terminology

We have based this update of the 2013 guideline on contemporary evidence-based guidelines [10, 14, 15, 31], scientific evidence from systematic reviews [17-22], randomized controlled trials [23, 24], observational studies [9, 25-30, 32-34], and expert opinion, involving experts from eight different disciplines involved in the treatment of people with diabetic foot disease. However, this should not be looked upon as an evidence-based guideline, as we did not follow a specific guideline development methodology. Developing evidence-based guidelines is an extensive and costly process. With recent studies providing a much stronger evidence-base for footwear requirements for people with diabetes we felt that a new footwear guideline to update information in the NHMRC guideline [31] and the 2013 Australian practical guideline on footwear provision [16] was more important than waiting for completion of a full evidence-based guideline. Compared to the recommendations from the 2013 guidelines, some have not changed, and a number of new ones have been added. These include the need for health professionals to prescribe medical grade footwear that has demonstrated plantar pressure reducing effects at high-risk plantar areas for those people with a healed plantar foot ulcer, to review the adequacy of any prescribed footwear every three months, and to treat a plantar foot ulcer primarily with appropriate offloading devices. With this current document, healthcare professionals can immediately start to implement the new footwear evidence to begin to further reduce the large national burden of diabetic foot disease.

The specific footwear requirements are closely related to an individual's foot risk status. This means that to provide people with diabetes with appropriate footwear, their foot risk status must be assessed first. We followed the classification as provided in the NHMRC guideline [31]. Other countries may use different risk classifications, and we advise healthcare professionals to ensure they use the guideline that is applicable in their own country with regard to foot risk status assessment. In this guideline, we did not separate between intermediate- and high-risk. The first reason for doing so was that some recommendations do not depend on foot risk status per se, but on the presence (or absence) of the specific risk factors of foot deformity or previously healed ulcer. To cover these differences, specific recommendations were needed that applied both to people at intermediate- and high-risk. Further, combining both groups while including specifically targeted recommendations also gives healthcare professionals from other countries the opportunity to match the recommendations in this guideline with their own country's foot risk status classification system. Finally, the recommendations that did not target a specific risk factor were similar for people at intermediate- or high-risk, which means they could be combined.

As recommended in this guideline, people at intermediate- or high-risk of foot ulceration

should be instructed to obtain their footwear from an appropriately trained professional with demonstrated competencies in footwear fitting for people with diabetes. We have not defined 'appropriately trained' or 'demonstrated competencies', as that was beyond the scope of the current document. However, as a minimum, we suggest an appropriately trained professional should be able to show documented evidence of their training and competency and should meet the standards of their profession when such standards are available. This way, other healthcare professionals may confidently inform people with diabetes where to obtain their footwear.

The methodology followed to write this guideline does have some limitations. The first, not following a guideline development methodology, has been discussed above. A second is that no patient advocates were involved in its creation. This is a consequence of not following a specific guideline methodology, and we hope that this will be done in the next update of the NHMRC guideline [31]. A third is the limited evidence base with regard to the recommendations for people at low-risk of ulceration [17, 41]. These recommendations might be seen as "good practice statements", a terminology used in official guideline development for recommendations that are predominantly based on expert opinion and standard of practice, when limited evidence is available [51]. As argued in other publications, it is hoped that researchers and healthcare providers combine efforts to build a stronger research evidence base for these recommendations [41]. Finally, we are unaware of cost-effectiveness information for any of the proposed footwear interventions [17], and thus no such specific information can be added to this guideline. However, a recent Australian cost-effectiveness analysis reported appropriately prescribed footwear as part of a suite of optimal diabetic foot care practice was always cheaper than standard care, and with the high costs associated with foot ulceration [1, 52, 53], it is likely that preventative footwear efforts in this regard will be cost-saving [41].

Conclusion

Appropriate footwear is important for all people with diabetes, to prevent foot ulceration and reduce the burden of diabetic foot disease. This guideline contains 10 key recommendations to guide health professionals managing people with diabetes choosing the most appropriate footwear for the person's specific foot risk needs. We hope that this guideline will be used to ensure that all Australians with diabetes have access to, and are provided with, appropriate footwear to meet their needs. This should improve footwear practice in Australia and reduce the burden of diabetic foot disease for people and the nation.

Abbreviations

IWGDF: International Working Group on the Diabetic Foot; NHMRC: National

Health and Medical Research Council

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JvN wrote the first version of the manuscript. PAL and PW provided critical review and expert opinion on this first version. A second draft incorporating consensus feedback from the three authors was sent to all authors, who provided critical review and their expert opinion. A third draft was written by JvN incorporating all feedback, and again sent to all authors. This process was repeated one more time, to reach consensus of all authors, leading to the final version of the guideline, approved by all authors.

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PRW: nothing to declare in relation to this manuscript.

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Website: www.akaishiusa.com

Amfit Inc. (1996)

Since 1977, Amfit has elevated custom foot orthotics in the computer age. From diabetic care to professional athletes and beyond – Amfit 3D contact technology offers innovative, user-friendly tools to create the exact results you desire. From small scale operations to large labs. Where technology fits. Perfectly. Amfit is your custom foot orthotic partner.

Vancouver, WA
Phone: (800) 356-3668
Fax: (360) 566-1380
Email: sales@amfit.com
Website: www.amfit.com

Apis Footwear Company (2000)

Mt. Emry therapeutic line - accommodate, never correct! We have the shoes to accommodate charcot, edema, hammer toes, bunions & RA.

Whether for depth, width or even for shape, select from our variety of styles to fit that special foot of your patient.

S. El Monte, CA
Phone: 626-448-8905
Fax: 626-448-8783
E-mail: sales@apisfootwear.com
Website: www.bignwideshoes.com

Apex Foot Health Industries (2019)

A member of OHI's growing family of companies focused on treating conditions and diseases of the lower extremities, Apex Foot Health Industries is widely recognized as a global leader in therapeutic footwear and orthotics.

Featuring the most comprehensive line of PDAC-verified diabetic shoes, Apex footwear provides superior comfort and protection in fashion-forward styles. Ideal for those requiring maximum adjustability, our advanced technological features and state-of-the-art materials help patients lead a healthy and active lifestyle.

Teaneck, NJ
(800) 252-2739
Fax: (201) 808-8155
Email: aorder@apexfoot.com
Website: www.apexfoot.com

Arizona AFO, Inc. (2003)

A member of OHI's growing family of companies focused on treating conditions and diseases of the lower extremities, Arizona AFO has been a premiere fabricator of custom-made ankle foot orthoses since 1994. Carrying on a tradition of innovation, excellence in manufacturing and exceptional customer care that began with company founder Ernesto Castro, Arizona AFO's steadfast focus on individual patient needs and patient outcomes continues headlong into the 21st century.

Arizona AFO launched an entirely new product category and moved its industry in a less invasive, non-surgical direction with its patented Arizona Brace®. Often copied but never equaled, the Arizona Brace® has been proven in clinical trials to effectively treat PTTD (Posterior Tibial Tendon Dysfunction). Arizona AFO is also the exclusive fabricator of the Moore Balance Brace™, the Optima Brace™ as well as a complete selection of other superior quality custom devices for treatment of even the most challenging cases.

All Arizona AFO products are designed, developed, manufactured and tested in the United States.

Mesa, AZ
Phone: (877) 780-8382; (480) 222-1580
Fax: (480) 480-222-1599
Email: info@arizonaafo.com
Website: www.arizonaafo.com

Bestsole, Inc. (2010)

We manufacture and distribute a glycerine-filled, therapeutic, massaging insole. Our insoles will massage your feet and increase circulation to your feet. They are also excellent shock absorbers for your feet, knees, hips and back. One pair fits in all shoes. Our insoles are machine washable. We offer a two-year replacement warranty. Our insoles have always been made in the USA. Visit our website for additional products.

Boynton Beach, FL
Phone: (866) 301-3338
Fax: (561) 547-4684
Email: bestsole3@bellsouth.net
Website: www.massaginginsoles.com

Bintz Company, Inc. (1991)

Distributor of pre-molded orthotics, comfort foot products, fitting aids and sheet goods. Products from Birkenstock, Birko

Orthopadie, Pedag, Powerstep, Spenco, Pedifix, Knit-Rite, Hapad, Rieckens PQ and more.

Wheaton, IL
Phone: (800) 235-8458
Fax: (630) 653-5077
Email: bintz@bintzco.com
Website: www.bintzco.com

BIRKENSTOCK

Birkenstock USA, LP (1990)

Birkenstock offers sandals, clogs, shoes, boots and arch supports all based on our original contoured cork footbed for women, men and children.

Birkenstock products are made in Germany, since 1774, and reflect our key values of health and wellness, quality, craftsmanship and environmental sensibility.

Novato, CA
Phone: (800) 949-7301
Fax: (415) 884-3250
Email: kwiltz@birkenstockusa.com
Website: www.birkenstock.com

BROOKS

Brooks Sports, Inc. (2001)

Brooks Sports, Inc., is proud of our hard-earned reputation for engineering footwear that provides the perfect ride for every stride.

Brooks works to ensure that all of our footwear products meet the biomechanical needs of runners, enhance comfort, and aid in the prevention of running-related injury.

We're dedicated to reducing running injury risk and have aligned ourselves with some of the top researchers around the work to tackle this.

Bothell, WA
Phone: (800) 2-BROOKS
Fax: (425) 483-8181
Email: shoeguy@seattleshoe.com
Website: www.brooksrunning.com

Bunion Bootie
BABY YOUR BUNIONS

Bunion Bootie (2014)

Say good-bye to painful rigid splints, pads that do not stay in place, and spacers that are difficult to walk in.

Bunion Bootie is the complete bunion treatment package; protective, supportive, comfortable, and not to mention, discreet. Truly one-of-a-kind in the world of bunion treatments. The newest in bunion treatment to help manage your bunion pain and best of all – it doesn't involve surgery!

San Luis Obispo, CA
Phone: (877) 208-4540
Email: Lisa@BunionBootie.com
Website: www.BunionBootie.com

C.N. Waterhouse Leather Co., Inc. (1998)

Manufacturer and distributor of fine leathers, woolskins, suede pig-skins, sheet goods and adhesives for use in the pedorthic footwear and orthopedic industries.

Hyannis, MA
Phone: (800) 322-1177
Fax: (508) 771-2300
E-mail: info@waterhouseleather.com
Website: www.waterhouseleather.com

Dr. Comfort

Dr. Comfort (2004)

Dr. Comfort manufactures, warehouses and distributes the finest quality extra-depth shoes for diabetics or patients who need quality comfort shoes.

Mequon, WI
Phone: (800) 992-3580
Fax: (262) 242-9300
Email: info@drcomfort.com
Website: www.drcomfort.com

Drew Shoe Corporation (1968)

Men's and women's depth and comfort footwear in over 150 sizes.

Lancaster, OH
Phone: (800) 837-3739
Fax: 740-654-4979
Email: customerservice@drewshoe.com
Website: www.drewshoe.com

Finn Comfort (1993)

Luxury comfort footwear. Men's and women's walking shoes, sandals and boots featuring removable/modifiable orthopedic footbeds. Hand-crafted in Germany.

Thousand Oaks, CA
Phone: 805-361-3466
Fax: 450-625-7886
Email: info@shopfinncomfort.com
Website: www.shopfinncomfort.com

Foot Solutions (2012)

Feet are your foundation for life. At Foot Solutions, we use the most advanced technology combined with a full understanding of biomechanics of feet and gait, along with the highest quality footwear on the planet to fit your unique feet. Through our customized solutions, we will improve your comfort and body alignment and help you achieve better health through your feet.

Marietta, GA
Phone: (888) FIT-FOOT
Fax: (770) 953-6270
Website: www.footsolutions.com

Frankford Leather Company, Inc. (1997)

Frankford Leather Co., Inc., is your single source supplier for your pedorthic shoe repair and shoe store supply needs. In stock, more than 8,000 products are available for immediate shipment.

Representing major brands and lines like Vibram, Soletech, Spenco, Powerstep, Pedifix, Pedors, Orthofeet, Kiwi; shoe care, adhesives, leather and more. Free catalog available.

Bensalem, PA
Phone: (800) 245-5555
Fax: (215) 244-4411
Email: sales@frankfordleather.com
Website: www.frankfordleather.com

Gadean Footwear (2010)

Gadean Footwear is the largest orthopaedic shoemaker in Australia.

Gadean Footwear provides retailers with washable slippers, motion shoes, fashion shoes, depth shoes, removable insole sandals and many more products.

Malaga, Western Australia, Australia
Phone: 61-8-92486533
Fax: 61-8-92486711
Email: info@gadeanfootwear.com.au
Website: www.gadeanfootwear.com.au

Goodhew, LLC (2012)

Goodhew, a leader in the ModernCraft movement, spins fresh designs, natural performance yarns, and the heritage of American craftsmanship to create high performance socks for the everyday world.

Goodhew: a sock for every walk in the walk of life.

Chattanooga, TN
Phone: 423-643-0821
Fax: 423-643-0825
E-mail: eeckardt@goodhew.us.com
Web site: www.goodhew.us.com

Guard Industries, Inc. (1996)

Components for shoe care, foot comfort, orthotics and prosthetics. Complete listing of available products will be sent upon request.

St. Louis, MO
Phone: (800) 535-3508
Fax: (314) 534-0035
Email: guard@il.net
Website: www.guardmfg.com

Haflinger/Highlander (Gerda Hoehm) (1999)

Boiled wool slippers, latex arch support, felt and leather clogs, cork molded footbed. Highlander is Gerda Hoehm's new high-quality comfort line with a removable footbed.

Both Haflinger and Highlander are made in Germany.

New York, NY
Phone: (212) 949-6767
Fax: (212) 949-8833
Email: haflingerny@worldnet.att.net

Hapad (1999)

Hapad is a leading manufacturer of 100% natural wool felt foot products and sports replacement insoles used for conservative management of common, painful foot complaints.

Correctly skived and adhesive backed for a quick and easy fit, Hapad products are an affordable alternative to custom made devices or they can be used to make custom modifications.

Bethel Park, PA
Phone: (800) 544-2723
Fax: (800) 232-9427
Email: info@hapad.com
Website: www.hapad.com

Honeywell Safety Products (2013)

NEOS overshoes provide a tough barrier between everyday footwear and the harsh elements of nature. Wear over your favorite,

comfortable shoes or boots with confidence that feet and footwear will stay warm and dry. NEOS are extremely lightweight and easy to get on and off. With different heights, insulation and traction to offer the right amount of protection, NEOS has you covered.

Smithfield, RI
Phone: (401) 757-2503
Fax: (401) 233-7641
E-mail: jennifer.stritzinger@honeywell.com
Website: www.honeywellsafety.com

ING Source, Inc. (2013)

ING Source, Inc. is a consumer health and medical device manufacturer selling products world-wide. Our origins were in design, development, sourcing and marketing consulting.

ING Source holds several patents, and is the creator of the innovative OrthoSleeve Branded products of FS6 Compression Foot Sleeve; CS6 Compression Calf Sleeve; KS6 Patella Knee Sleeve; ES6 Compression Elbow Sleeve; and the DermaSox Foot Treatment System.

ING Source also offers OEM for compression wear and orthopedic support in sports, rehabilitation and Diabetic Foot Care to numerous premium brands.

Hickory, NC
Phone: (828) 855-0481
Fax: (877) 635-1521
E-mail: dhiggins@ingsource.com
Website: www.ingsource.com

J.H. Cook & Sons, Inc. (2004)

Shoe modification components, foot comfort products and shoe repair supplies. Products from Aetrex, Spenco, Vibram and Soletech.

Granite Quarry, NC
Phone: (704) 279-5568
Fax: (704) 279-5261
Email: jhcooka@windstream.net

JMS Plastics Supply (1992)

JMS is the first U.S. company to have Silpure in our nylon top cover on our Neolon. Silpure is an advanced anti-microbial protection that provides proven anti-bacterial properties of silver. Available in 1.5 mm and 3.0 mm sheets. Our Neolon with Bamboo is also deodorizing and anti-bacterial and comes in sheets 40" x 48" or 48" x 80". Our new J-fab line of prefabs are thin, heat moldable and they come in three styles and three colors.

Neptune, NJ
Phone: (800) 342-2602
Fax: (732) 918-1131
E-mail: sales@jmsplastics.com
Website: www.jmsplastics.com

Justin Blair & Company (2001)

Manufacturer of Ralyn Shoe Care and Backroom Supplies and NightCare Foot Care. Distributor for Aetrex, Acor, Darco, Herbal Concepts, Pedifix, Swede-O, Silipos and Therafirm.

Chicago, IL

Phone: (800) 566-0664
Fax: (773) 523-3639
Email: orders@justinblair.biz
Website: www.justinblairco.com

KLM Laboratories (2006)

An industry leader in the manufacture of foot orthotics and insoles, specializing in custom orthotics, pre-fabricated orthotics, orthotic insoles and orthotic materials.

Valencia, CA
Phone: (800) 556-3668
Fax: (800) 556-3338
Email: cservice@klmlabs.com
Website: www.klmlabs.com

Landis International (2014)

Landis International Inc., a Canadian manufacturer and distributor of orthopedic and shoe repair machineries, is the undisputed leader and the Industry's main supplier for North America and Australia. Landis International offers new and reconditioned quality equipment, tools, as well as the necessary parts required for the maintenance of equipment built to last a lifetime.

800, Rossiter Saint-Jean-sur-Richelieu
(Québec) Canada J3B 8J1
Phone: 1-450-359-8800
Toll-free: 1-800-634-0806
Fax: 1-450-359-9619
Email: info@landisinternational.ca
Website: http://landisusa.com

Lord Custom Molded Shoes, Inc. (1994)

Fashionable custom-molded shoes for men, women, and children. Guaranteed fit and service.

Bohemia, NY
Phone: (800) SHOES11
Fax: (516) 471-3090
Website: www.lordshoes.com

mediUSA, LP (2013)

Our company slogan "medi. I feel better." reflects our view of ourselves as a partner to everyone who operates in the medical aids market

With our products and technologies, we would like to make people's lives easier, better and more comfortable. We aim to do this by meeting the different needs of all our customers, every day and throughout the world.

"I feel better" is therefore a promise that becomes a reality with medi, because we offer indication-specific and effective product solutions to the highest standards, which, with the help of our pioneering, individual concepts and dense customer service network, can be provided wherever they are needed.

Whitsett, NC
Phone: (800) 633-6334
Fax: (888) 570-4554
E-mail: edw@mediusa.com
Web site: www.mediusa.com

Mephisto (1998)

With worldwide headquarters in Sarrebourg, France, MEPHISTO - the WORLD'S FINEST FOOTWEAR, was founded more than 40 years ago by Martin Michaeli. Mephisto has a loyal following and a strong international reputation for comfort and quality. Its high-quality handcrafted footwear styles include sandals, boots, clogs, dress and classic walkers, as well as the ergonomic brand, Mobils. In recent years, the company also introduced the more athletic inspired brand, Allrounder by Mephisto and their latest collection with superior toning technology, Sano by Mephisto.

Franklin, TN
Phone: 800-775-7852
Fax: 615-771-5935
E-mail: info@mephistousa.com
Web site: www.mephisto.com

Miami Leather Company (2001)

Wholesaler to the orthopedic, prosthetic, retail shoe and shoe repair trades. Wide variety of products.

Miami, FL
Phone: (305) 266-8328
Fax: (305) 266-8728
Email: sales@miamileather.com
Website: www.miamileather.com

Nolaro24, LLC (2015)

Nolaro24, LLC is the Maker of Quadrastep and littleSTEPS foot orthotics - the first Patented custom to foot type prefabricated foot orthotics for adults and kids, the Next best thing to Custom!

Middlebury, CT
Phone (Toll Free): (877) 792-4669
Website: www.thequadrastepsystem.com
Email: info@thequadrastepsystem.com

National Shoe Specialties & Biotime Footwear (2014)

National Shoe Specialties & Biotime Footwear (2014)

For over forty years National Shoe has taken pride on providing exceptional service to our customers by offering:

- Leading, Reputable and Premium Quality Brands
- A Knowledgeable and Professional Sales Team
- Unparalleled Customer Service

Our relationships are built on a foundation of trust, respect and a desire to partner in the continued success of our customers and vendors through innovation and continuous improvement. At National Shoe we offer an

extensive material & footwear selection for the Pedorthic/ Orthopaedic/Prosthetic, Shoe Store and Repair channels of business across Canada and the United States

Toronto, ON
Phone: 800-387-5246
Fax: 800-568-8930
Websites: www.nationalshoe.com
www.biotimefootwear.com

New Balance (1990)

New Balance, headquartered in Boston, MA supports a family of brands including New Balance, Aravon, Dunham, PF Flyer, Warrior and Brine. All brands specialize in sizes and widths across a number of categories including running, walking, training, kids, comfort casual, lifestyle, team sports and apparel.

Boston, MA
Phone: (617) 783-4000
Fax: (617) 783-7050
Website: www.newbalance.com

New Step Orthotics (2015)

At New Step Orthotics our mission is to provide quality orthotics and services that reflect our effort to a quality product with excellent customer service. We offer a 7 day in house turnaround on all custom foot orthotics. We offer free in-bound shipping to our customers and a 1 year product warranty. Family owned since 2004.

Maryville, IL
Phone: 866-798-7463
Website: www.newsteporthotics.com

PartnerShip (2000)

The PFA Shipping Program, managed by PartnerShip, features discounted shipping rates with FedEx®, UPS Freight® and YRC. PFA members can enroll in this free member benefit and take advantage of savings on every shipment – inbound, outbound, business to business, business to consumer, express, small package ground, tradeshow and LTL freight - all with no shipping minimums or requirements. For more information or to enroll today please visit http://www.partnership.com/micro-site/index/57pfa, call 800-599-2902 or email sales@partnership.com.

Cleveland, OH
Phone: (800) 599-2902
Fax: (800) 439-8913
Website: www.partnership.com

PediFix, Inc. (2001)

Foot specialists since 1885, PediFix is the only fourth generation, family-owned business in the pedorthic industry. Choose from more than 150 quality foot treatment products, including a unique OTC line guaranteed to generate cash sales, keystone profits and doctor referrals, an assortment of both traditional and exclusive Visco-GEL foot pads and cushions, new dermatology products, GelStep silicone insoles and orthotics, Diabetic Solutions Socks, PediPlast and more. 15 new products are being introduced this year.

Contact PediFix today for a free color catalog.

Brewster, NY
Phone: (800) 424-5561
Fax: (845) 277-2851
Email: sales@pedifix.com
Website: www.pedifix.com

Propet USA, Inc. (2000)

Leading manufacturer in men's and women's comfort walking shoes. Available in up to 5 widths, sizes 5-13 in women's, 7-17 in men's. Propet features a vast selection of Medicare A5500 coded footwear with removable orthotics, secure closure and maximum customization.

Kent, WA
Phone: (800) 877-6738
Fax: (800) 597-8668
Email: customerservice@propetusa.com
Website: www.propetusa.com

Remington Products (2000)

Insoles and sheet packages, rigid arch supports, viscoelastic heel cups, 3/4 and full insoles.

Wadsworth, OH
Phone: (330) 335-1571
Fax: (330) 336-9462
Email: jwert@remprod.com
Website: www.remprod.com

Renia GmbH (2001)

Specially designed adhesives and components for the shoe industry, shoe repair trade, and O & P industry.

Cologne, Germany
Phone: 49-221-6307990
Fax: 49-221-63079950
Email: info@renia.com
Website: www.renia.com

SAS Shoemakers (1992)

Comfort walking shoes for women and men in a wide range of widths and sizes.

San Antonio, TX
Phone: (210) 924-6561
Fax: (210) 921-7460
Email: barmwood@sas-shoes.net
Website: www.SASshoes.com

STS Company (1997)

Resin-impregnated tubular and fitted socks made to take foot and ankle impressions for custom shoes and foot/ankle orthotic devices.

Mill Valley, CA
Phone: (800) 787-9097
Fax: (415) 381-4610
Email: info@stssox.com
Website: www.stssox.com

Shoe Systems Plus, Inc. (2003)

Complete line of orthotic and prosthetic equipment including finishers/grinders, vacuum pans, pumps, presses, industrial sewing machines, fume busters and more.

Goshen, NY
Phone: (800) 354-6278
Fax: (845) 291-7097
Email: shoesystemsplus@hvc.rr.com
Website: www.shoesystemsplus.com

SoleTech, Inc. (1994)

SoleTech Inc., established in 1946, has a full line of cushioning and fabrication materials for the pedorthic footcare industry. Soletech introduced its registered brand Cloud EVA and Soleflex EVA in the early 1980s and is now recognized as the industry leader for materials for the fabrication of custom foot orthotics and AFOs and components for build-ups and modifications to extra-depth and custom footwear. In addition to its presence in the orthopedic market, SoleTech is also a leading supplier of footwear components and materials to the shoe manufacturing and shoe repair industries.

Claremont, NH
Phone: 603-542-8905
Toll Free: 877-625-9494
Fax: 603-542-8909
Email: tom@soletech.com
Website: www.soletech.com

Sole Supports, Inc. (2012)

Sole Supports is an innovative, medical-grade foot orthotics manufacturer. We make custom foot supports that follow your doctor's prescription in order to provide both immediate pain relief and prevention of any new pains or deformities. Medical practitioners must first be certified to order from us because we offer a completely different type of support than the ones for which they were trained in school and because we must have the best possible cast of your foot to make the best support.

Lyles, TN
Phone: 931-670-6111
Fax: 931-670-6008
E-mail: info@solesupports.com
Website: www.solesupports.com

Spenco Medical Corporation (2013)

Spenco is an innovative healthcare company whose mission is to help people everywhere achieve more comfortably.

While Spenco's core business revolves around producing high quality insole and footcare products, Spenco also provides the most advanced sports medicine and first aid products.

Above all else, customer service is Spenco's focus and we are 100% committed to providing outstanding service as we help you find the solutions for all of your health and footcare needs

Waco, TX
Phone: (800) 877-3626
E-Mail: jeffa@spenco.com
Website: www.spenco.com

Spira (2004)

Spira® is an advanced footwear brand premised upon a patented and patent pending footwear technology called WaveSpring® Technology. Which helps protect against fatigue, stress, shock and impact forces.

The Spira family consists of several walking and running models available in up to 4 widths.

Los Angeles, CA
Phone: (866) 838-8640
Fax: (915) 838-8641
E-Mail: Kevin@spira.com
Website: http://spira.com

Streifeneder USA (1997)

Preformed insoles, diabetic shoes and materials in different hardnesses, especially for diabetics.

Tampa, FL
Phone: (800) 378-2480
Fax: (813) 246-5998
E-mail: euro@eurointl.com
Website: www.eurointl.com

Superfeet Worldwide LLP (2003)

Ferndale, WA
Phone: (360) 384-1820
Fax: (360) 384-2724
Email: here@superfeet.com
Website: www.superfeet.com

TechMed 3D (2011)

TechMed 3D is an easy to use, accurate, and portable solution for the digital acquisition of images and measurements of human body parts, giving orthotists, prosthetists and pedorthists access to very reliable and consistent measurements.

Levis, Quebec, Canada
Phone: (418) 836-8100
Fax: (418) 836-1589
Email: info@techmed3d.com
Website: www.techmed3d.com

Therafirm (A Division of Knit-Rite, Inc.) (1999)

Quality medical-grade compression hosiery and diabetic socks.

Ellerbe, NC
Phone: (800) 562-2701
Fax: (910) 652-2438
Website: www.therafirm.com

Tekscan, Inc. (1994)

Broad range of pressure assessment and clinical/research evaluation tools for use in orthotics, brace evaluations, joint biomechanics, and gait analysis.

Boston, MA
Phone: (617) 464-4500
Fax: (617) 464-4266
Email: marketing@tekscan.com
Website: www.tekscan.com

Thor-Lo, Inc. (2001)

Statesville, NC
Phone: (704) 872-6522
Fax: (704) 838-6323
Website: www.thorlo.com

Treadlabs (2017)

Foot-care professionals agree that orthopedic arch support is more effective than soft foam for sustained relief of foot pain.

If you are in the market to buy orthotic insoles, consider Tread Labs' 30-day fit guarantee, free shipping and free returns. Order with confidence, knowing that your arch support orthotic insoles are risk free.

Stoneham, MA
Phone: (781) 435-0662
Fax: (716) 881-0406
Email: hello@treadlabs.com
Website: https://treadlabs.com

Tru-Mold Shoes, Inc. (1980)

Tru-Mold Shoes offers a complete line of contemporary, fully accommodating custom-molded shoes, including the Thera-Medic Shoe package – the most flexible, highest value shoe package for Medicare-eligible patients with diabetes.

Buffalo, NY
Phone: (800) 843-6653
Fax: (716) 881-0406
Email: info@trumold.com
Website: www.trumold.com

Trufit Orthopedic Labs (2013)

Trufit Biomechanics Labs is a full service biomechanics and podiatric company. We manufacture individually engineered CAD/CAM corrective foot orthotics in the USA.

We operate multiple chiropractic and podiatric patient-care facilities across Europe.

In addition to operating several patient clinics in Europe, we continuously engage in highly funded research and development projects in conjunction with several European government laboratories as joint ventures that have become very successful in developing new patient care evaluation techniques and innovative medical corrective devices, grounded in science

Our commitment to Research, Development and Innovation is a foremost goal, and we only employ medical, engineering, and computer science professionals who share that vision.

Orlando, FL
Phone: 855-910-2525
Fax: 321-202-2819
E-mail: info@trufitusa.com
Website: www.trufitusa.com

UniStyle Footwear (2017)

Since 2003, UniStyle Footwear has been manufacturing fashionable comfort, orthopedic and custom footwear. UniStyle Footwear provides quality handcrafted footwear according to rigorous quality standards and use the best natural materials, quality leathers, and breathable lining.

North York, ON M3J 2R8
Phone: (416) 638-7000
Fax: (416) 638-7627
Email: oumanskiinc@bellnet.ca
Website: www.unistyleshoes.ca

Value Foam, Inc. (2014)

Value Foam Inc. is devoted to offering our customers high quality, low cost materials commonly used for orthotic and prosthetic devices. Bring us your current invoice, we will be happy to offer you the same type of materials at 10 percent less.

Our product lines include high quality EVA, AccuZote (a more economic substitute of plastazore) and PPT/SBR materials at various density and thickness.

South El Monte, CA
Phone: (800) 788-1358
Fax: (800) 788-1358
E-mail: mary@valuefoams.com
Web site: www.valuefoams.com

Vibram USA (1998)

Since 1937, Vibram has stayed true to its heritage by building products focused on quality and performance while keeping the end user in mind. Each sole, heel or rubber component is built with proprietary compounds and endless quality control. We are also proud to say that we produce millions of soles each year in one of the last rubber soling plants in the USA - the Quabaug Corporation in North Brookfield, MA.

Concord, MA
Phone: (978) 318-000, ext. 136
E-mail: sales@vibramusa.com
Website: http://us.vibram.com

Ziera Shoes N.Z., Ltd. (Formerly Kumfs Shoes N.Z., Ltd.) (1998)

Ziera Shoes, formerly Kumfs Shoes, are women's shoes, sandals and boots that are truly orthotic friendly. Ziera Shoes come in a wide range of heeled fashion and walking footwear. We have widths in stock from M through XXW in sizes 34 through 45.

Port Orchard, WA.
Phone: 877 717 0588
Fax: 877 717 0589
Email: craig.taylor@zierashoes.com
Website: www.zierashoes.com

ADVERTISING QUESTIONS

The advertiser index is published for the readers' convenience. Click on the hyperlink to take you to the advertiser's website. If you have any questions about advertising, please contact our advertising sales representative:

To contact our **Sales Manager:**
Phone: (229) 389-3440
Or email: **advertising@pedorthics.org**

ADVERTISER	PAGE	WEBSITE
ABC (American Board for Certification in Orthotics, Prosthetics and Pedorthics, Inc.)	ICF	abcop.org
Acor	pg. 4	acor.com
Apis	pg. 38	apisfootwear.com
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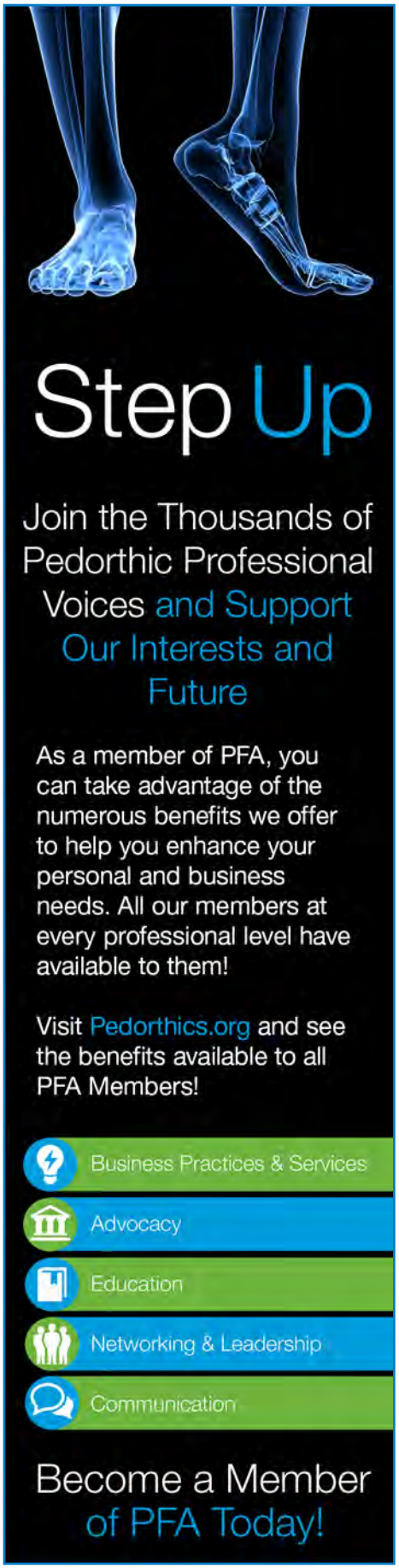

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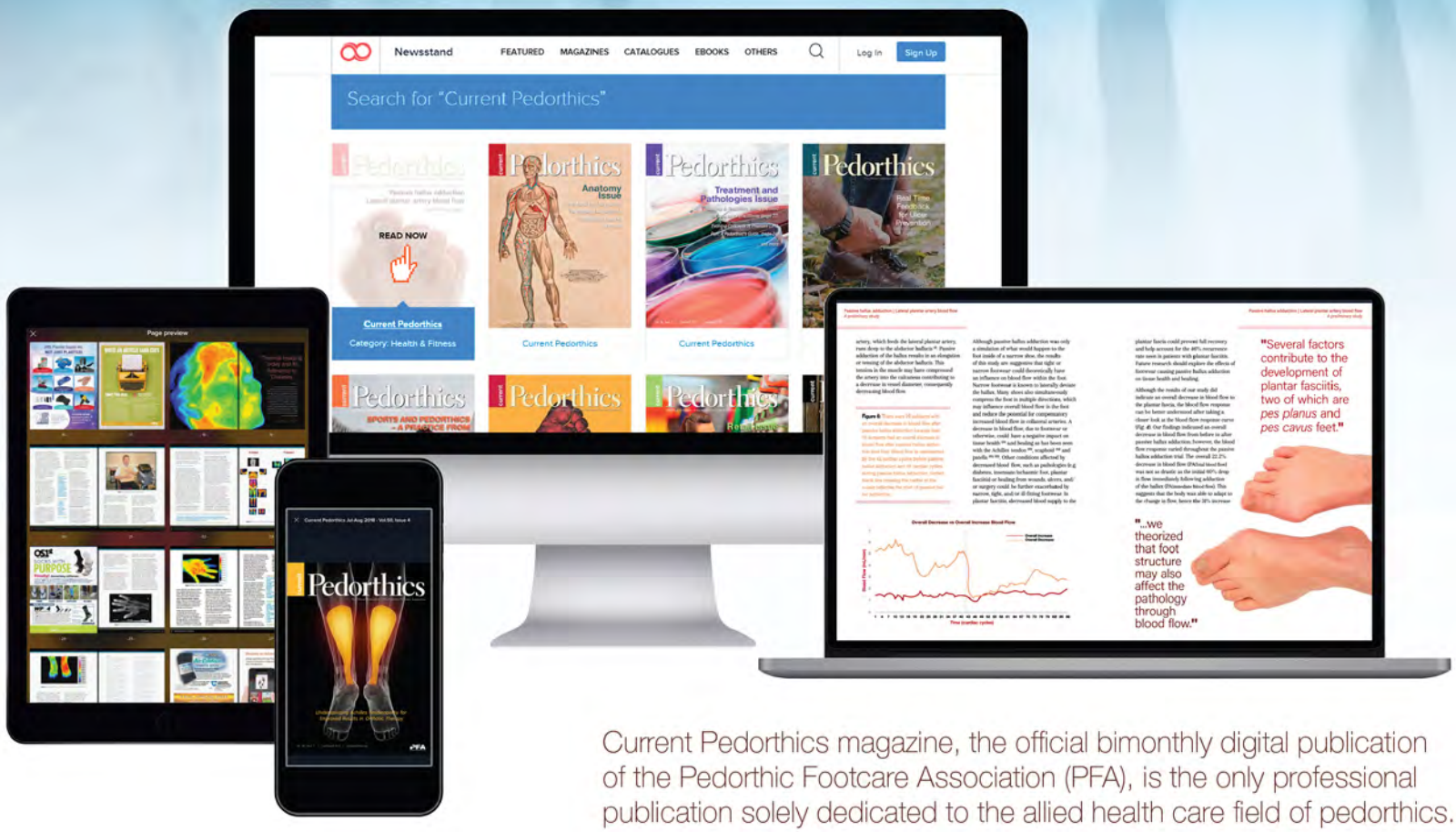

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