Therapeutic Footwear for the Neuropathic Foot

An algorithm

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Neuropathy may bring about changes in form and function of the foot, which may lead to ulceration and progressive deformity. These manifestations often require specially adapted footwear. A comprehensive concept of the medical, functional, and technical requirements for this type of footwear is still lacking to date. In this article, we present an algorithm that should facilitate prescription and manufacture of adequate shoes. This algorithm attempts to establish a link between the requirements from a medical and functional point of view and the technical possibilities of orthopedic shoe technology.

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The neuropathic foot is characterized by loss of peripheral nerve function, which can be sensory, motor, autonomic or, usually, a combination of these. This loss of function causes changes in the form and function of the foot and may lead to ulceration and severe deformity, which eventually may result in amputation (1). Therefore, protection of the foot is of the greatest importance. In addition to a careful lifestyle, appropriate footwear is essential for achieving this protection (1,2).

In medical literature on the neuropathic foot, much has been written about the prevention of complications. The importance of "good footwear" is stressed, though frequently without further specification (3,4). So far, research has focused only on parts of the problem, mostly pressure reduction (5–8), although in addition to peak pressure, the duration of maximum pressure and shear stress are also important (9–11). Diabetic footwear has been discussed in descriptive articles (12, 13) and technical studies (8,14). However, the authors confine themselves to specific aspects like pressure distribution and rocker-bottom outsoles (8,14). A comprehensive conceptual approach for the management of the various aspects of this footwear problem is still lacking (15). The rationale behind footwear prescriptions is often unclear to patients and healthcare workers alike, and this can diminish compliance (3,16).

The aim of this article is to describe the relationship between medical requirements and technical possibilities. For this purpose, we have developed an algorithm. A number of its components are evidence-based, but most are opinion-based, because testing the effects of therapeutic footwear is impossible without clear guidelines. This algorithm aims at establishing guidelines for clinical treatment and further research into this complex subject.

REQUIREMENTS BASED ON MEDICAL FEATURES

Altered biomechanics in the foot may lead to ulceration and progressive deformity (17). Here, we will only discuss the different features of a neuropathic foot. Because neuropathy commonly occurs in diabetes, we will also mention one of its consequences, limited joint mobility, which is not directly related to neuropathy (18).

1. Sensory dysfunction

1.1. Loss of sensory function

In the long term, reduction of sensory function may lead to complete loss of sensation in the foot. We speak of loss of protective sensation when the patient is not aware of external damage. In general, these patients are unable to detect the 5.07 Semmes-Weinstein filament (19).

In this situation, a shoe that is neither too tight nor too roomy is appropriate (13). The shoe must also be adapted to any other characteristics of the foot, e.g., ulcer or deformity.

1.2. Loss of sensory function together with autonomic neuropathy

A consequence of autonomic neuropathy is a warm dry skin in which even slight pressure and friction is sufficient to cause excessive callus formation. To avoid this, an insole should provide optimal distribution of pressure, reduction of shear stress, and shock absorption (7,12,13). Care should be taken to ensure that this insole leaves enough room for the foot.

2. Limited joint mobility

This condition results in a generalized stiffness of the foot (18). Initially, the forces will be transmitted unaltered to the hindfoot during heel strike. This leads to reduced shock absorption within the foot during gait. Later on, friction between the forefoot and the shoe will occur during push-off because of reduced dorsiflexion in the forefoot (20).

Limited joint mobility (LJM) requires a shoe with shock absorption through the heel, a toughened outsole, a rocker-bottom sole, and an insole that distributes pressure evenly (7,8,12,13).

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Abbreviations: LJM, limited joint mobility; MTP, metatarsophalangeal joints.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

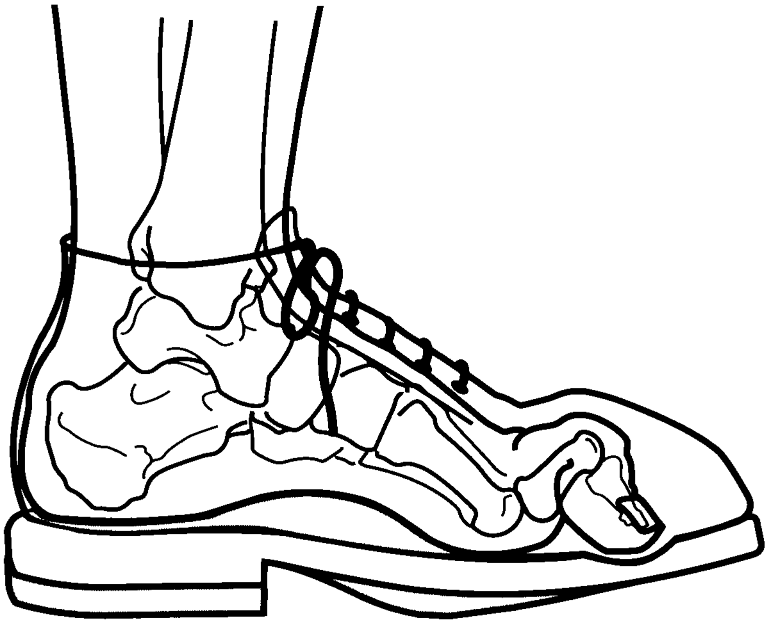

Figure 1—*Bottine shoe with a full-contact insole and a rocker bar with an early pivot point.*

3. Deformities
3.1. Hollow-claw foot
Paresis of the intrinsic foot muscles leads to an imbalance favoring the extrinsic foot muscles, resulting in hyperextension of the proximal phalanges and flexion of the distal phalanges. The plantar aponeurosis tautens, and the result is a hollow-claw foot. This is a stiff foot with little shock absorbency, a reduced supporting area, and an inability to push-off, because the metatarsophalangeal joints (MTPs) are already at maximal dorsiflexion.

This foot requires a shoe with maximal pressure distribution by means of a full-contact insole, a toughened outsole with an early pivot point, and shock absorption through the heel (5,12,13). In a low shoe, the foot is not fixated well enough, and a high shoe is not strictly necessary. For this condition, an ankle-high shoe is recommended (Fig. 1).

3.2.1. Flexible flatfoot with hallux valgus
Paresis of the extrinsic foot muscles, particularly the tibialis posterior, causes the collapse of the longitudinal plantar arch, resulting in a flatfoot with a hallux valgus. The weakened foot musculature is unable to store any transformation energy, so there is little shock-absorbing capacity (10,16).The abnormal position of the foot causes a great deal of pressure on its medial edge. The hallux valgus makes normal push-off impossible, creating enormous friction on the medial side of MTP-1.

This condition requires a high shoe that corrects the position of the foot by means of an insole and strong high medial support (4,5,8,12). In addition, this condition requires a rocker bar under the shoe and shock absorption via the heel (13).

3.2.2. Rigid flatfoot with hallux valgus
The main therapeutic goal here should be to stop the condition deteriorating any further. If a fixed deformity is not properly accommodated, excessive pressure will be exerted on the medial border of the foot (13).

Therefore, strong medial support is required. An ankle-high shoe is permissible, because no attempt at correction is being made. A rocker bar with an early pivot point and a toughened outsole with shock absorption via the heel is required (13).

3.3. Charcot foot (neuro-osteoarthropathy)
The changes in the forces in the foot combined with osteoporosis (a consequence of autonomic neuropathy) can damage the skeleton of the foot and its associated ligaments (10). This gives rise to a foot with bony deformities as well as the following decreased functions mentioned above in the sections on LJM, hollow-claw foot, and flatfoot: insufficient shock absorbing capacity, abnormal distribution of pressure, and limited push-off (11,21).

An active Charcot foot should be immobilized in a plaster cast until the condition has stabilized ("cooled-off") and the required footwear is ready (22). A cooled-off Charcot foot requires a shoe that prevents further collapse of the foot, similar to a plaster cast (1,13). In other words, it requires a high, stiffened shoe that has a full-contact insole and a rocker-bottom sole with an early pivot point and shock absorption through the heel.

4. Partial foot amputation
4.1. Hallux amputation
Amputation of the hallux in a neuropathic foot always has a dramatic effect on gait. The pressure distribution is altered (23), and push-off takes place over the distal part of the first metatarsal bone, causing much friction there. After push-off, the shoe cannot return to the neutral position, causing wrinkling of the leather of the uppers. This can cause pressure ulcers on the dorsum of the foot.

This situation can be corrected by fitting the shoe with a rocker bar with an early pivot point (13). Wrinkling of the uppers can be eliminated by the use of a stiff outsole. Experience shows that the patient's foot slips easily in this type of shoe; therefore, ankle-high shoes are recommended. To relieve the pressure on the distal edge of the foot, an insole with maximal pressure distribution is recommended (1).

4.2. Forefoot amputation
The same conditions as in section 4.1 apply to forefoot amputation, but in this case, there is a high risk of the foot going into an equinovarus position with peak pressures on the distal lateral edge of the foot (24). Because of stiffness, there is inadequate shock absorption.

This condition requires a high shoe that relieves the pressure on the distal edge of the foot. This is achieved by making a rocker-bottom sole with an early pivot point (13,14). Maximal fixation of the foot in the shoe is obtained by using the three point principle: forces are transmitted through a stiff sole, leg, and tongue. Shock absorption takes place through the heel.

5. Ulceration
If ulceration is present, it is essential to discover its cause. It can arise from poor circulation or from trauma. However, it is

Figure 2—*Rehabilitation shoe (i.e., temporary orthopedic shoe) that is high and has a stiff leg and outsole, a rocker bar with an early pivot point, and a full-contact insole.*

commonly caused by unnoticed pressure or friction in the shoe (9). Possible causes include a change in the shape of the foot without a corresponding change in the footwear or the noncompliance of the patient with regard to advice on lifestyle or footwear (3).

Ulcers can be healed quite effectively by the use of a plaster cast (25,26). The same effect may be achieved by the use of a custom-made high shoe. This shoe must have an optimal fit and a stiffly constructed leg, tongue, and outsole; a rocker-bottom sole with an early pivot point; and shock absorbency through the heel and outsole (5,13).

TECHNICAL POSSIBILITIES OF A SHOE

A shoe is made of a number of different parts and possesses a number of characteristics, which are discussed here. We like to emphasize that an insole can only influence pressure distribution; it can never reduce friction. Because reduction of friction requires optimal fixation of the foot inside the shoe, a stiffened construction and a rocker bar under the shoe are required (14).

All the different parts of the shoe have their own requirements, which are closely interrelated. If this interrelationship is ignored, the shoe will have a detrimental effect on the foot. Technically, there are a number of possibilities for fulfilling these requirements, including adaptation of off-the-shelf shoes or the use of orthopedic or semiorthopedic shoes (see definitions). As a temporary measure, a rehabilitation shoe (Fig. 2) is a good interim solution, whereas a medical shoe seldom is. Because customs and possibilities differ from country to country, we will not discuss the materials for insoles and uppers, the techniques in preparing the lasts, or the possible shoe styles; instead, we will limit ourselves to biomechanical needs and solutions.

A. Insole

In the neuropathic foot, the insole must always be custom-made. The function is pressure reduction via the principle of full contact with shock absorbing material or, locally, total relief of pressure via a cutout in an otherwise full-contact surface (5,12,13,16,26).

B. Shoe height

The height of a shoe can be categorized into three types: high, bottine (ankle-high), and low (Fig. 3). High shoes are necessary for the transference of forces: for correction, relieving the pressure on a particular part of the foot, and immobilizing the foot in the shoe. This can also be accomplished by using an ankle-foot orthosis in combination with shoe adaptations (27), but this can have a negative effect on walking velocity and cosmesis (14). Bottine shoes are used if the foot has a tendency to slide forward in the shoe.

C. Outsole profile

A rocker-bottom profile can have its pivot point at different levels. In cases of limited mobility of the forefoot, a rocker bar with the pivot point at the level of the MTPs is sufficient; we call this a normal pivot point (Fig. 4). When relief of MTPs is necessary, the pivot point needs to be proximal of the MTPs (13); we call this an early pivot point (Fig. 1). A rocker bottom profile always requires a toughened or stiff outsole.

D. Outsole flexibility

An outsole can have different degrees of flexibility: stiff, toughened, or supple. A stiff outsole is necessary for the reduction of pressure in one particular area of the foot, correction of the foot shape, and immobilization of the foot in the shoe. This inflexibility is needed because, using the three-points principle, the three sides must be stiff to facilitate the distribution of forces exerted on the foot.

An outsole should be toughened if

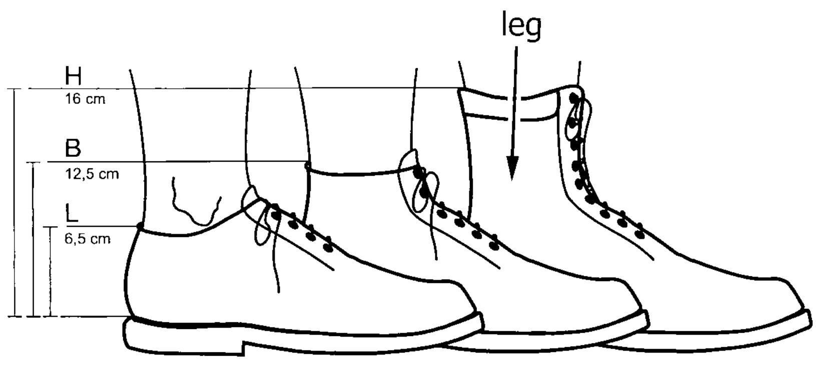

Figure 3—*Shoe height. Diagram shows high* (H)*, bottine* (B)*, and low* (L) *shoes.*

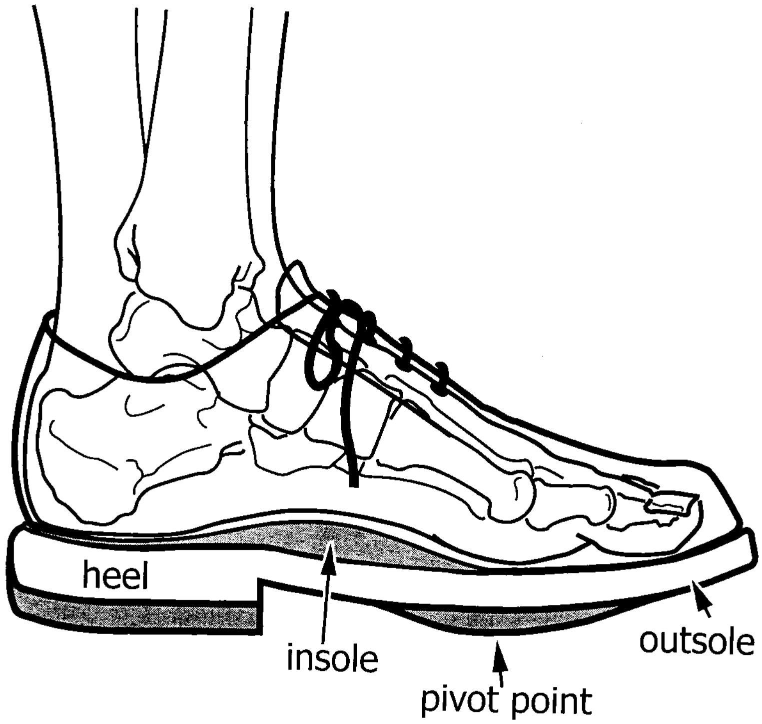

Figure 4—*Low shoe with a full-contact insole and a rocker bar with a normal pivot point.*

there is only limited mobility in the foot (13). The shoe should never be more supple than the foot, otherwise friction between the foot and shoe will develop during push-off. In the remaining cases, a supple sole is sufficient.

E. Leg

The leg also has various degrees of flexibility, which are related to the degree of flexibility of the outsole. A stiff outsole combined with a high supple leg results in wrinkling of the shoe and friction between the foot and shoe. A long medial counter is used to obtain optimal pressure distribution over the medial edge of the foot in a flatfoot.

F. Tongue

A completely supple tongue has the tendency to sag, thereby causing wrinkling. In principle, the degree of flexibility of the tongue should be the same as that of the outsole and leg. However, in practice the required degree of stiffness can usually be achieved with just a toughened tongue, together with a high stiff leg and a strong high closure method.

G. Heel

The heel may be made of resilient material to increase shock absorbency (13). In the case of a mild drop-foot, the back of the heel may be rounded to curb the dropping of the foot.

CONCLUSION— In this article we have discussed the demands made on a therapeutic shoe from a medical point of view. We have also looked at the technical requirements and possibilities and at how the different types of adaptation are interlinked. In the absence of evidence for the necessity for patients with neuropathic feet to wear therapeutic footwear, we have attempted to establish a connection between these two perspectives by creating an algorithm (Table 1) that, out of necessity, had to be based on experience for the most part. We have successfully used this algorithm in daily practice, and we think that in the future it will enable us to judge the results of treatment of the neuropathic foot.

Definitions

Off-the-shelf footwear. Shoes available from normal shoe outlets.
Semiorthopedic footwear. Factory-produced shoes that have been formed by using both a high last, which creates space to accommodate an abnormally shaped foot, and a custom-made insole. If necessary, adaptations, such as a rocker-bottom sole or a rounded heel, may be added.
Orthopedic footwear. Custom-made shoes. These shoes are handmade for individual patients, and they can incorporate all of the requirements.

Table 1—*Algorithm: therapeutic footwear for the neuropathic foot*

	Medical features	Insole	Shoe height	Pivot point	Outsole	Leg	Tongue	Heel
1.1	Sensory loss	no	low	NA	supple	supple	supple	normal
1.2	Sensory and autonomic dysfunction	yes	low	NA	supple	supple	supple	resilient material
2	Limited joint mobility	yes	low	normal	toughened	supple	supple	resilient material
3.1	Hollow-foot with claw toes	yes	bottine	early	toughened	toughened	toughened	resilient material
3.2.1	Flexible flatfoot with hallux valgus	yes	high	normal	toughened	toughened	toughened	resilient material
3.2.2	Rigid flatfoot with hallux valgus	yes	bottine	early	toughened	strong medial support	toughened	resilient material
3.3	Charcot foot	yes	high	early	stiff	stiff	toughened	resilient material
4.1	Hallux amputation	yes	high	early	stiff	toughened	toughened	resilient material
4.2	Forefoot amputated	yes	high	early	stiff	stiff	stiff	resilient material
5	Ulceration	yes	high	early	stiff	stiff	toughened/stiff	resilient material

NA; not applicable.

Rehabilitation shoe (i.e., temporary orthopedic shoe). A custom-made shoe of pliant material that can generally be delivered within 2 weeks of ordering. All necessary adaptations can be incorporated into their design (Fig. 2).

Medical shoe. A factory-made soft slipper-style shoe made on a high last. Space is created for insertion of a custom-made insole and for accommodation of the bandaged foot.

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