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# **Diabetic Foot Care within the Context of Rehabilitation: Keeping People with Diabetic Neuropathy on their Feet.**

## **A Narrative Review**

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**Running title:** Rehabilitation and diabetic foot care

# **Abstract**

## **Background**

A large percentage of patients with diabetes mellitus have neuropathy putting them at risk of developing severe foot problems. In diabetic foot care the primary objective is to prevent foot ulceration and avoid loss of limb. The role of physical therapy in diabetic foot care remains insufficiently defined. This narrative review discusses principles of diabetic foot care and implications for rehabilitation.

## **Objectives**

The objectives are to review:

- which aspects of current diabetic foot care are relevant for rehabilitation.
- how and where physical therapy expertise can contribute to diabetic foot care.
- how physical therapy can safely design an exercise program when patients have diabetic neuropathy.

## **Major Findings**

The diabetic foot is a complex condition. Current best practice involves care by a multi-disciplinary team. Physical therapy should adhere to key elements of foot ulcer prevention. The effect of reduced balance and mobility resulting from foot ulceration and its treatment indicates a need for bespoke exercise programs. During full weight-bearing exercises protective footwear should be worn at all times. Furthermore, a good understanding of the impact of functional exercises used in rehabilitation with respect to plantar pressure and postural control needs to ensure that exercise prescription is appropriately targeted and safe.

## **Conclusions**

Physical therapy can make a considerable contribution to overall management of patients with diabetic neuropathy. A tailored exercise program to improve fitness, strength, range of motion, balance and mobility should be aimed primarily at keeping patients with diabetic neuropathy safely on their feet and improve clinical outcomes.

**Keywords:** diabetic foot, foot ulceration, plantar pressure, rehabilitation, physical therapy

## Background

Many patients seen routinely in rehabilitation will have diabetes mellitus. It is therefore important to be fully aware of the complications that often come with this condition. Boulton et al.<sup>1</sup> reported that neuropathies can affect up to 50% of people with diabetes coinciding with an estimated incidence of foot ulceration of at least 2% of the total population in developed countries. Bakker et al.<sup>2</sup> warned that a large number of diabetic foot ulcers do not heal which subsequently leads to some form of amputation. In fact, diabetes mellitus is now the leading cause by far of lower limb amputations<sup>1</sup>. In our work as clinicians the majority of patients with lower limb amputations were treated for diabetic foot complications. Typically rehabilitation was more difficult because contralateral foot problems required attention. However, diabetic foot management is not only important at this late stage of the disease process but at all times and in all clinical settings. The contribution physical therapy can make to prevention and management of diabetic foot complications within the context of general health and well-being seems insufficiently recognised. Furthermore, the physical therapy literature remains limited in this area. Consequently, the format of a narrative review was used to allow us to draw from a variety of sources. We primarily aimed to use systemic reviews and clinical guidelines discussing management of the diabetic foot and/or neuropathy. This was complemented by published research on specific topics in rehabilitation identified through targeted searches in Ovid Medline, CINAHL, Scopus, Google Scholar and Cochrane Library databases. Besides clinical experience, the first author has spent many years doing research on diabetic neuropathy and was a member of the working group which published systematic reviews and clinical guidelines for the International Diabetes Federation. Both authors have worked together on delivering in-service training about diabetic foot care to local hospital physical therapy services. Most of the literature used will probably not be very familiar in physical therapy circles and this review aims to provide an initial guidance.

The evidence base for diabetic foot care has been increasing substantially in recent years<sup>3</sup>. Particularly the International Working Group on the Diabetic Foot (IWGDF) has been instrumental in producing a collection of systematic reviews and clinical guidelines covering relevant areas<sup>2</sup>. The documents resulting from this effort are available on the IWGDF website ([www.iwgdf.org](http://www.iwgdf.org)) and are a good, comprehensive resource for those involved and interested in diabetic foot care. NICE guidelines<sup>4</sup> with respect to the prevention and management of diabetic foot problems is an equally important resource. The challenge of diabetes, diabetic neuropathy, foot ulceration and limb amputation has been very persistent. Jeffcoate and van Houtum<sup>5</sup> reported that up until the year 2000, the overall incidence of amputation for diabetes in the US was unchanged and that the results for Europe were inconclusive. In fact, the problem was made worse by the growing number of people with diabetes<sup>6</sup>. However, there seem to be indications that diabetic foot management in specialised clinics using the latest clinical guidelines are starting to have a positive effect<sup>1, 7, 8</sup>. It is therefore with great urgency that Bakker et al.<sup>2</sup> called for increased awareness and appropriate action to ensure quality foot care based on these clinical guidelines are widely adopted by clinicians and therefore available to patients.

## **Objectives**

The objectives of this narrative review are to discuss:

- which aspects of current diabetic foot care are relevant for rehabilitation.
- how and where physical therapy expertise can contribute to diabetic foot care.
- how physical therapy can safely design an exercise program when patients have diabetic neuropathy.

## Major Findings

### *Diabetic neuropathy and foot ulceration*

Diabetic neuropathy degrades the sensory, motor and autonomic peripheral nerves and therefore affects foot function in multiple ways. When loss of plantar cutaneous sensation is severe enough protective sensation will be affected<sup>9</sup>. This means that people will not be able to detect trauma to their foot. Additionally, proprioception arising predominantly from muscle receptors may be reduced<sup>10</sup> resulting in problems with balance and motor control. This will be further exacerbated by the loss of muscle strength in the lower limbs<sup>11</sup> which may to some extent be attributed to motor neuropathy. Other factors such as lack of physical exercise will of course play a role in loss of muscle strength. There is a complex relation between motor neuropathy, foot deformities and ulceration risk<sup>12</sup>. For instance, hammer and claw toes coincide with a more prominent position of the meta-tarsal heads. Plantar fat-pad thinning and displacement will reduce cushioning of these same meta-tarsal heads. Therefore, normal protection against mechanical loading of these bony prominences will be decreased. Autonomic neuropathy is associated with peripheral sudomotor dysfunction and altered microvascular skin blood flow which is related to skin dryness, fissures and cracking and excess callus formation<sup>13, 14</sup>. Autonomic neuropathy also appears to affect bone mineral density which has been linked to midfoot (Charcot) fractures<sup>15</sup>. Besides neuropathy, peripheral artery disease and ischemia are important factors<sup>16</sup>. Although this is by no means a comprehensive overview of all factors that can result in the condition called diabetic foot it does make it clear that the etiology is complex. Consequently, there is no single pathway to foot ulceration; instead ulceration is mostly due to multiple factors conspiring to cause skin breakdown. On the one side, sensory neuropathy, ischemia and infection related to the complications of diabetes mellitus<sup>17</sup> are important factors for risk of ulceration. On the other side, mechanical stress substantially contributes to ulceration risk<sup>17</sup>.

As mentioned before, the loss of protective sensation will lead to a loss of awareness when trauma occurs. Minor trauma caused by small objects inside the shoe<sup>18</sup> can go unnoticed and progress to breakdown of the skin. Everyday walking results in frequent and repeated high plantar pressures especially over the forefoot<sup>9</sup>. The healthy foot is normally competent to withstand such stress. However, a number of structural changes in the diabetic foot such as foot deformities related to motor neuropathy<sup>12</sup> excess callus over the plantar surface<sup>9</sup> and limited joint mobility<sup>19</sup> result in higher than normal plantar pressure during walking<sup>17</sup>. The reduced ability of the plantar tissues to cope with these stresses adds to the risk of injury. Once the skin is ulcerated, the wound is susceptible to becoming infected. It should be no surprise that the diabetic foot ulcer is difficult to treat successfully and that all efforts will be directed towards this objective.

### *Reasons why physical therapy needs to be more involved in diabetic foot care*

Typically, the treatment of diabetic neuropathy and its complications, particularly plantar ulceration, should be provided by a multi-disciplinary team<sup>3</sup>. Multi-disciplinary foot clinics are considered the key strategy to optimise diabetic foot care. It should be noted that physical therapy has not been identified as a key profession for these foot clinics<sup>3, 20</sup>. Physical therapy

is thought to play a beneficial role in the treatment process external to these foot clinics<sup>20</sup>. However, this role has not been clearly defined.

Ideally, physical therapy should be more actively involved in the prevention and management of diabetic foot problems at all stages of diabetes. Traditionally however, it is only at the later stage of complications when patients have undergone lower limb amputations that physical therapy is involved by providing rehabilitation. Even at this stage it is important to consider these same aspects of foot care and limb salvage. The misinterpretation that the non-amputated side is the so-called “healthy side” seems easy to make. It is very important to note that diabetic neuropathy is a condition which affects both limbs similarly because diabetic neuropathy is normally a symmetrical condition<sup>21</sup>. Therefore, the contra-lateral side requires monitoring and management just as much as the amputated side. The contralateral side is put at risk of ulceration further when the amputation of one limb causes increased loading of the contralateral limb particularly in the context of mobility and activities of daily living involving weight-bearing<sup>22, 23</sup>.

The primary objective in the treatment of the diabetic foot is obviously to avoid that foot ulceration will occur and that ulceration will lead to loss of limb. This focus on limb salvage will mean that walking is primarily viewed as problematic since biomechanical loading of the foot increases the risk of ulceration. Within this context the definition of foot function will be limited to the ability to safely bear weight on the feet and to walk a short distance. Within rehabilitation treatment objectives are used in the broader framework of functioning as defined in the International Classification of Functioning (ICF)<sup>24</sup>. Foot function in this broader context requires attention to patient activity and participation: fitness, ability to walk and carry out all activities of daily living as needed and in the amount desired by each individual; and the ability to participate in social activity for instance related to work, recreation, sport, family and friends. Diabetic foot problems can lead to a loss of activity<sup>23, 25</sup> and patients will receive advice to limit their walking as part of ulcer treatment. Inactivity in and of itself is problematic for people with diabetes<sup>26</sup>. Additionally, peripheral neuropathy affects postural control resulting in an increased risk of falling<sup>27-30</sup>. Postural instability and lack of physical activity will further complicate the clinical management of the diabetic foot. It therefore appears that diabetic neuropathy can lead to a catch 22 situation where the patient is advised to limit walking to heal and protect their feet and at the same time is advised to walk regularly to help control their weight and improve cardiovascular fitness and glycaemic control<sup>31</sup>. It is with respect to this dilemma in treatment that physical therapy can make its biggest contribution.

### ***Prevention of diabetic foot complications and implications for rehabilitation***

Based on the various IWGDF clinical guidelines, Schaper et al.<sup>18</sup> have published a summary guidance which rehearses key points for the prevention and management of foot problems in diabetes. They highlighted five elements that are essential for prevention (see Table 1) and seven elements essential for treatment of diabetic foot complications. We will use this as a basis for the following discussion which aims to identify relevance for rehabilitation. With respect to prevention, all healthcare professionals have a duty of care to identify the at-risk foot in patients with diabetes by routinely carrying out foot inspection. The pre-ulcerative signs to look out for include: abundant callus, cracks and fissures, blisters, ingrown or

thickened nails, and fungal infections. Also peripheral artery disease, foot deformities, skin dryness, and poor foot hygiene are important to note. When such pre-ulcerative signs are observed referral to a trained foot care specialist would be the required action to take<sup>4</sup>. Referral is also indicated when footwear is not appropriate or worn out. An urgent referral in case of foot ulceration or re-ulceration should be self-evident<sup>4</sup>. Note that ulceration does not always present as an open wound. Skin discoloration indicating a subcutaneous haemorrhage can be the first presentation which later develops into an open ulcer<sup>18</sup>. It is important to realise that many cases of diabetic neuropathy can go unnoticed for a long time and problems may only reveal themselves at the time an ulcer has occurred. Inspecting the feet for pre-ulcerative signs requires removal of shoes and socks so that the feet can be visually inspected and tested for sensation. Sensation testing over critical areas of the foot using the recommended 10 gram monofilament and other tests have been very clearly explained in the review by<sup>18</sup> and therefore we refer to their paper for details.

[Table 1 near here].

Protective footwear is an important element of prevention of diabetic foot complications. The most important aim is to achieve a substantial reduction of peak pressure over the plantar surface of the feet. This also known as offloading. There are a number of systematic reviews that discuss footwear for prevention and treatment of diabetic foot ulceration<sup>32-37</sup> as well as clinical guidelines<sup>38</sup>. However, comprehensive clinical evidence does not exist yet in this area leaving important questions insufficiently answered. That means that expert opinion has to be used to fill in the blanks for the time being. Typically, podiatrists, shoemakers and/or casting technicians will be involved in the provision of protective footwear depending on which country and location you are working in. It is important to interact and collaborate with these healthcare professionals to help optimise this important aspect of care. Shoes that people may prefer to wear because they are fashionable are often not appropriate for protecting their feet from injury. Protective footwear generally will have a more bulky appearance and tends to be less popular for that reason. Loss of sensation will mean that discomfort from ill-fitting shoes will not necessarily be detected. In fact, patient perceptions are not a good guidance for choosing appropriate footwear. In one of our biomechanical studies<sup>39</sup> the control shoe which was a soft, adaptable shoe made from foam material was rated very highly in terms of comfort by all study participants who had diabetic neuropathy. However, the biomechanical effect of this control shoe was non-existent since plantar pressure was no different to barefoot walking. All effective special footwear tested in this study was rated much lower for comfort by these same participants. The considerable reduction of plantar pressure over important areas of the foot in this special footwear were however significant and clinically relevant. In the context of evidence-based practice, footwear with a demonstrated effect of reducing plantar pressure as measured by in-shoe pressure measurement should therefore be recommended<sup>38</sup> and not on the basis of patient perception. It is evident that those who do adhere to wearing effective protective footwear do better in terms of avoiding foot ulceration/re-ulceration<sup>40</sup>. Recognising that adherence to treatment is a complex issue<sup>41</sup>, all healthcare practitioners should aim to use empathy as they repeat and reinforce the messages in health education that support adherence to protective footwear since this ultimately is an

important element of limb salvage. Poor adherence should lead to a referral back to the person who made the protective footwear so that it can be reviewed. Figure 1 intends to illustrate that appropriate use of footwear in hospital also requires attention. Based on anecdotal evidence, patients with or without diabetic neuropathy often choose inappropriate footwear. Besides hygienic considerations, these slippers will not have helped reduce plantar pressure at all for this patient with diabetic neuropathy. In fact, the left slipper would certainly add pressure to the heel area and the collapsing right slipper may be contributing to increased plantar pressure as well. Healthcare providers alert to the risk of loss of protective sensation and increased plantar pressure leading to ulceration are more likely to take appropriate action to improve the situation pictured in Figure 1.

[Figure 1 near here].

Table 2 lists the items that should be part of the education as recommended by Schaper et al.<sup>18</sup>. These messages should be delivered repeatedly and consistently by healthcare providers to patients, partners, carers, and/or other family. Self-inspection of the feet, if necessary with help of special shatterproof mirrors is done at least daily and after walking outdoors. Important to remember is that walking barefoot carries unacceptable risk. Anecdotally, there are examples where people did not notice stepping on a small insulin needle or a piece of broken glass hidden in the carpet whilst walking barefoot at home. When a foreign body is diagnosed much later using X-ray the decision for surgical removal is made difficult because this might further compromise the condition. Walking barefoot on the beach would pose a similar risk because of sharp objects such as broken shells. Physical therapists should therefore also discourage barefoot walking at all times. Also stepping into a hot bath with feet first poses a high risk.

[Table 2 near here].

### ***Treatment and management of diabetic foot ulcers and implications for rehabilitation***

In the acute phase of ulcer treatment the emphasis will be on relief of pressure and protection of the ulcer, restoration of skin perfusion, treatment of infection, metabolic control and treatment of co-morbidity, local wound care, supported by education for patient and relatives<sup>18</sup>. Once healed there is a high risk of ulcer recurrence so that ulcer prevention becomes even more important. For many of these treatment aspects physical therapy will not be heavily involved. However, it is important to realise that it tends to take a long time for ulcers to heal; it can take months and even years in some cases. This will have a big impact on everyday mobility and quality of life<sup>42</sup>. Typically, patients will be supplied with more substantial offloading footwear to largely remove pressure over the ulcerated area. Depending on the country where treatment is provided this will be a total contact cast or some sort of walking brace<sup>37</sup> often reaching up to the knee. Since it is not always easy to walk with such devices this intervention tends to seriously restrict mobility<sup>43</sup>. In fact, because of this it has

proved difficult for patients to adhere to offloading interventions and when they were able to remove their device there is evidence that they do<sup>40</sup>.

Many devices used for ulcer treatment provide a reduced base of support and often introduce a leg length discrepancy if not corrected so that they are difficult to walk with normally and affect balance. Since postural control is often already affected this will provide additional challenges for maintaining balance and mobility<sup>30</sup>. Reducing the risk of falling is an area where physical therapy can make a major contribution. Practicing safe mobility and balance training with ulcer treatment footwear possibly with help from a walking aid would be important objectives. Based on their study, Nahas et al.<sup>44</sup> advise to minimise leg length discrepancy to avoid increased plantar pressure for the contra-lateral foot. This recommendation also might be relevant for prevention of low back pain although no studies have explored this problem specifically.

Alternative forms of plantar offloading exist but these have their own drawbacks. Staying in bed or using a wheelchair until the ulcer has healed could mean a prolonged period of inactivity for many patients. For instance, obesity and cardio-vascular fitness is often already a concern<sup>26</sup> and further reductions of physical activity would be undesirable in this context. Alternatively, it would be possible to use a set of crutches to entirely offload the foot. However, as mentioned earlier both feet are affected by diabetic neuropathy. Therefore, offloading one foot by using swing-to or swing-through gait with crutches or a walking frame could easily result in more stress to the contra-lateral, weight-bearing foot. This style of ambulation may have a negative effect on balance and increase the risk of falling. Furthermore, the stresses of full weight-bearing on the arms and/or the contra-lateral leg could be unacceptably high, especially in the presence of co-morbidities such as osteoarthritis.

As mentioned before, the primary goal of the multi-disciplinary team managing diabetic foot problems is to salvage the limb and they will do this at great cost. The decision to start to amputate is not made lightly and correctly so. Patients may undergo a series of partial foot amputations before they are ever seen by physical therapy. The effect of a partial foot amputation is a major challenge for those providing appropriate footwear. The foot might heal with some difficulty causing a long wait before patients can be mobilised properly again<sup>45</sup>. The removal of part of the foot means that the plantar surface area is reduced. During walking and weight-bearing activities, the ground reaction force magnitude will not be reduced. Consequently increased pressure will be applied over the remainder of the plantar surface<sup>46-48</sup>. The structural foot changes resulting from the amputation are expected to alter foot function and ankle range of motion (ROM) with the risk of developing into an equinus deformity, potentially influencing the plantar pressure distribution as well as the ability to maintain balance. The risk for ulcer recurrence and falling is therefore increased. It seems reasonable to involve physical therapy to a greater extent at this stage to help patients with their recovery. In particular prolonged periods of inactivity should be avoided by agreeing a bespoke strategy to be as physically active as possible. Maintaining ankle ROM seems an important treatment objective as well<sup>47</sup>. Close collaboration with the healthcare professionals who provide the special footwear should be aimed at literally keeping patients safely on their feet.

As indicated earlier, the effect of foot ulceration and reduced mobility on health-related quality of life should not be underestimated. In fact, in her review Price<sup>42</sup> highlighted that this may be worse for patients with diabetic foot ulceration than when they have undergone an amputation. The fear of ulcer recurrence with repeated infection and the threat of a life-long disability seem to be driving this. In addition, restrictions in participation in normal social life are experienced by both these patient groups. Interestingly, interaction with a multi-professional team to learn to understand their condition and to become more hopeful for the future seems to have a positive effect on the risk of diabetic foot complications<sup>42</sup>. Clearly, physical therapy can contribute to managing these psychological effects.

### ***Rehabilitation of patients with diabetic neuropathy***

Despite best efforts to avoid the sequence of diabetes, diabetic neuropathy, foot ulceration and partial foot amputation, many of these patients eventually end up in rehabilitation to receive physical therapy for a major amputation. Clinical guidelines exist for rehabilitation of the adult lower limb amputee<sup>49</sup>. These guidelines give reasonable attention to the problem of diabetic neuropathy. Rather than discuss these guidelines, aspects of rehabilitation will be considered in a broader context. This is because there will be a large number of people undergoing rehabilitation for a variety of other conditions who will have diabetic neuropathy as a co-morbidity<sup>1</sup>. Since diabetic foot care has already been discussed in the sections above, specific aspects of rehabilitation will be considered in the context of diabetic neuropathy here.

For patients with complications related to diabetes, the risk of prolonged periods of reduced activity is substantial<sup>50</sup>. There is a large body of literature that demonstrates the benefits of physical exercise for glycaemic control. In their systematic review and meta-analysis Boulé et al.<sup>51</sup> concluded that physical exercise significantly reduces glycosylated haemoglobin (HbA1c) which is suggested to decrease the risk of diabetic complications. Further systematic reviews and meta-analyses have shown that both aerobic and progressive, resistive exercises have this beneficial exercise effect<sup>52, 53</sup>. Therefore, in general physical therapy expertise is required for maintaining an appropriate physical exercise routine. The use of progressive resistance exercises for the lower limbs seems to offer opportunities to achieve a positive effect with respect to glycaemic control whilst at the same time improving the loss of muscle strength typically seen in diabetic neuropathy.

White et al.<sup>54</sup> in their Cochrane review reported from 3 studies that there was some evidence that muscle strengthening exercises in the presence of peripheral neuropathy was moderately effective to increase strength in the tested muscles. However, this increase did not affect functional ability. Smith et al.<sup>55</sup> did a similar systematic review of the effect of exercise in peripheral neuropathy using an increased number of studies. Their conclusion was that there is supporting evidence for muscle strengthening exercises. At least one study demonstrated that these exercises also resulted in functional benefits with respect to walking. They speculated that the response to exercise was generated by the muscle fibres not yet affected by axonal degeneration related to the peripheral neuropathy. Smith et al.<sup>55</sup> also mentioned the importance of flexibility/range of motion exercises particularly for the ankle joints. However, there is a need for more studies before a definitive conclusion can be drawn about effective exercises.

Loss of plantar cutaneous sensation<sup>9</sup> and reduced ankle proprioception<sup>10</sup> observed in diabetic neuropathy negatively affects postural control and balance resulting in an increased risk of stumbling and falling<sup>27-30</sup>. Each year 30% of all people over the age of 65 fall at least once<sup>56</sup>. The same study<sup>56</sup> reported a fall incidence per year of 39% in the group over 65 with diabetic neuropathy. According to Richardson et al.<sup>57</sup> the incidence of falling in this group is doubled. However, robust evidence for this was not provided. Studies to date appear to have used small samples. The risk of falling is in any case substantial. A review for the general elderly population exploring the consequences of falling reported that after a fall about 20% will require medical attention<sup>58</sup>. A fracture or another serious injury occurs in 5%<sup>58</sup> with death occurring in about 0.46%<sup>59</sup>. More research into the incidence and the consequences of falling in diabetic neuropathy is required.

A number of systematic reviews have explored the effect of balance and falls prevention programs for people with diabetic/peripheral neuropathy. Ites et al.<sup>60</sup> concluded that one study provided support for the use of lower extremity strengthening to improve balance as measured by a number of functional scores. Gu and Dennis<sup>61</sup> reported on ten studies evaluating falls prevention programs in people with diabetic neuropathy. Typically programs were about 60 minutes using approaches such as strengthening exercises, balance exercises, Tai Chi, and walking/aerobic exercise. Benefits were defined more by means of functional outcome measures than by changes in the incidence of falls. Further studies to determine the optimal intervention as well as its intensity and frequency are needed. Gu and Dennis<sup>61</sup> mention that there were some reports of adverse events. This included complaints such as calf strain and pains. More worryingly, minor foot ulcers and lesions occurred during one of the walking/aerobic exercise programs. Therefore despite the fact that evidence supports fall prevention programs, continuous vigilance is required when weight-bearing exercises are used because of the risk of foot ulceration.

Gait re-education and training is an important part of rehabilitation. For the patient with diabetic neuropathy it has already been pointed out that weight-bearing comes with an inherent threat. Protective or therapeutic footwear for outdoor and indoor use is essential at all times. Appropriate footwear should always be an integral part of rehabilitation and exercise prescription. When using weight-bearing activities and exercises, foot inspection should be routine. Where patients with diabetes may generally be advised to walk on a daily basis for the benefit of their health and fitness it will be important to consider adaptation of this recommendation when patients have a high risk of ulceration. In that case non-weight-bearing exercises such as swimming and partial weight-bearing exercises using static bikes or stair climbers would provide good opportunities to stay fit and healthy whilst plantar pressure is kept within limits<sup>62, 63</sup>.

A number of studies have demonstrated that altered walking patterns can help reduce plantar pressure<sup>64-67</sup>. For instance, slower walking and shuffling or step to gait will significantly reduce forefoot pressures. This has been proposed as an intervention to help prevent foot ulceration. However, whether this is feasible and patients will adhere to this style of walking in real life is difficult to predict. Therefore this approach should be questioned when something as serious as potential loss of limb is at stake.

The evidence for the use of walking aids for reduction of plantar pressure is unfortunately very limited. Kwon and Mueller<sup>67</sup> reviewed available evidence in this area. They cited a

reduction in peak pressure over medial forefoot areas of around 20% when using a single walking stick. This should be interpreted as a rather limited effect in terms of plantar offloading. These results suggest that the main role of a walking stick is to provide stability and enhance proprioceptive feedback during walking<sup>68</sup>. Since the use of a walking stick or crutches has not been demonstrated to be an adequate alternative, protective footwear should be considered as the primary intervention to achieve offloading for prevention of foot ulceration.

In rehabilitation functional activities are used to exercise and mobilise patients. Rozema et al.<sup>69</sup> and Guldemond et al.<sup>70</sup> studied how these affect plantar pressure and demonstrated that level walking produced the highest forefoot pressures compared to a variety of other activities. Walking with a change of direction considerably increased plantar pressure compared to straight line walking. Rao and Carter<sup>71</sup> directly compared plantar pressure during level walking with stair ascent and descent. Level walking produced higher peak plantar pressures compared to stair walking. That may not be intuitive but biomechanical studies can help explain these findings. As a general rule, the amount of forefoot push off required for an activity is the crucial factor to consider. About 40-50% of power is generated by ankle plantar flexion during level walking<sup>72</sup>. Winter & Sienko<sup>73</sup> even reported up to 80% of power generated at the ankle for gait. Peak ground reaction force (GRF) during gait at push off is 1.1-1.2 times bodyweight (BW)<sup>74</sup> which will determine how much plantar pressure will occur over the forefoot. Alterations in power generation during stair walking could explain why plantar pressures were slightly reduced compared to walking. The peak GRF for stair ascent and descent are similar to what is observed for level walking<sup>75</sup>. However, during what is called the pull up phase for stair ascent and the controlled lowering phase for descent power is generated predominantly at the hip and knee<sup>76</sup>. Ankle push off plays a less important role in stair walking compared to level walking.

In summary, there is some evidence for appropriate use of exercise in rehabilitation of patients with diabetic neuropathy. This includes exercises to improve aerobic capacity, muscle strength, range of motion, balance and mobility. Safe delivery of a tailored exercise program means that the risk of foot ulceration and of falling is carefully addressed. More scientific evidence is clearly needed before specific exercise guidelines can be developed in more detail.

## **Conclusions**

This narrative review aimed to set out where physical therapy can make its contribution to diabetic foot care. It would appear that a considerable role can be played not only in usual care for prevention and management of the diabetic foot but also by introducing aspects of treatment that are currently receiving insufficient attention. In particular, the effect of reduced mobility resulting from foot ulceration is problematic. Protective and therapeutic footwear seems to have a further negative effect on balance, mobility and the ability to maintain healthy levels of activity. Therefore, physical therapy should develop bespoke exercise programs aimed at keeping patients with diabetic foot problems on their feet; i.e. reducing their risk of falling without increasing the risk of foot ulceration. An important role for partial

and non-weight-bearing exercises seems obvious. During full weight-bearing exercises protective footwear needs to be used at all times. Furthermore, routine foot inspection after exercise is essential and referral to a trained foot care specialist is required if any pre-ulcerative signs are observed. A good understanding of the biomechanical impact of exercises and functional activities used in rehabilitation with respect to plantar pressure and postural control would ensure that exercise prescription can be appropriately targeted and is safe. The diabetic foot is a difficult condition to manage but with increased awareness how physical therapy can contribute to its multi-disciplinary treatment clinical outcomes can be further improved.

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**Table 1:** The five key treatment elements used for prevention of diabetic foot problems (from Schaper et al.<sup>18</sup>).

- (1) Identification of the at-risk foot
- (2) Regular inspection and examination of the at-risk foot
- (3) Education of patient, family and healthcare providers
- (4) Routine wearing of appropriate footwear
- (5) Treatment of pre-ulcerative signs

**Table 2:** Education about the risk of diabetic foot ulceration should include the items listed below (from Schaper et al.<sup>18</sup>).

- Determine if the person with diabetes is able to perform a daily foot inspection. If not, discuss who can assist the person in this task. A substantially visually impaired person cannot adequately do the inspection
- Perform daily foot inspection, including areas between the toes
- Notify the appropriate healthcare provider at once if foot temperature is markedly increased, or if a blister, cut, scratch or ulcer has developed
- Avoid walking barefoot, in socks without footwear, or in thin-soled standard slippers, whether at home or outside
- Do not wear shoes that are too tight, have rough edges or uneven seams
- Inspect and feel inside all shoes before you put them on
- Wear socks/stocking without seams (or with the seams inside out), do not wear tight or knee-high socks and change socks daily
- Wash feet daily (with water temperature always below 37 °C), and dry them carefully, especially between the toes
- Do not use any kind of heater or a hot-water bottle to warm feet
- Do not use chemical agents or plasters to remove corns and calluses; see the appropriate healthcare provider for these problems
- Use emollients to lubricate dry skin, but not between the toes
- Cut toenails straight across
- Have your feet examined regularly by a healthcare provider

## Figure captions

**Figure 1:** Example of inappropriate footwear used by a patient with diabetic neuropathy in a hospital ward.

