The F-Scan in management of diabetic patients with high risk for neuropathic ulceration

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Introduction

Complications seen in patients with diabetes such as peripheral neuropathy and peripheral arterial disease can lead to ulceration, infection and loss of limb. While neuropathy has been recognised as the main aetiology for foot ulceration because of the loss of pain protective sensation, foot ulceration usually occurs in the area of the foot subjected to high mechanical pressure [1, 2]. The body responds to the high pressure by developing thicker skin, called a callus, to protect the area of high pressure.

In patients without loss of sensation, the normal response to repetitive stress caused by high pressure area is inflammation. This sends pain signals to the brain to tell the body to modify the gait pattern to avoid pain. In response, the stress is relieved, allowing tissue damage to be repaired.

For patients with loss of sensation, the brain does not receive any danger signals, therefore the repetitive stress continues without any tissue repair in progress. The callus continues to build up, causing further elevation of plantar pressure in that skin region, increasing the risk of ulceration [3].

A 30 month prospective study at a diabetes centre showed that 35 per cent of patients with high plantar foot pressure developed ulceration [4]. There are many factors that can contribute to the recurrence of foot ulceration [5] but it has been shown that patients who were compliant to wearing protective footwear designed to reduce peak plantar pressure reduced the recurrence of foot ulceration by greater than 50 per cent [6]. Knowledge of which area under the foot produces higher pressure when walking can only help the clinician in providing proper shoes or shoe inserts for the patient so that they can help prevent development or recurrence of foot ulceration.

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Foot anatomy

The human foot is a highly dynamic structure composed of 26 bones held together by many ligaments and stabilised by many intrinsic muscles with their tendons. The skin provides a barrier to the environment, including bacteria. However, dry skin is a frequent problem in diabetic patients as a result of autonomic neuropathy. The dry skin can become hardened and cause increased pressure at heel contact, leading to ulceration. Furthermore, the cracks and fissures can harbour bacteria and lead to ulceration and severe infection.

The intrinsic muscles stabilise the foot while the extrinsic muscles produce motion for ambulating. For patients with neuropathy, the intrinsic muscles can become atrophied with resulting foot imbalance. Subsequently, the digits must work harder to grip the ground in gait to maintain balance, resulting in claw toe and hammer toe deformities. The stronger extrinsic muscles pull on these hammer toes unopposed; this retrograde force makes the metatarsal heads more prominent, leading to higher metatarsal head pressure. Additionally, patients with diabetes with charcot neuropathy frequently develop a rocker-bottom foot deformity that is prone to increased pressures in the midfoot region.

The gait cycle

The normal gait cycle consists of the swing phase and the stance phase. The stance phase begins with heel strike and ends with toe lift following propulsion and covers 60 per cent of the gait cycle. The body receives double support from both limbs during this phase. At heel strike, the high ground reactive force is absorbed by the subtalar joint and fat pad. This force moves forward along the lateral column and is then shifted medially to the first metatarsal head where the push-off is high. If the foot is unable to distribute the weight during the stance phase due to any bony prominence, abnormally high plantar pressure can develop. Charcot neuroarthropathy has been implicated as a cause of bony changes and therefore results in abnormally increased plantar pressure at points not along the normal ground reactive force.

Plantar foot pressure measurement

Foot pressure measurement has been a topic of interest for decades. In 1882, Beely described one of the earliest studies used to evaluate foot pressure; he had subjects walk over a sack filled with plaster of Paris to produce footprints.

Another earlier method involved having subjects walk or stand on carbon paper overlaying unsoiled paper. Areas of high direct pressure will leave an imprint on the clean paper underneath.

Advancements led to the development of Prescale pressure sensitive films consisting of two films. One layer is coated with a microcapsule containing colour producing agent which ruptures when pressure is applied. The second layer is coated with a colour developing agent that will display colour of various densities depending on the amount of pressure applied [7].

Morton described the use of the kinetograph, a deformable rubber pad that made contact with inked paper underneath as the subject walked over the pad [8]. Elftman later developed a barograph [9], which is a rubber pad with a pyramidal projection on the bottom. As subjects walked over the pad on a heavy glass plate, a movie camera recorded the deformation pattern of the pad from below. Acran and Bull [10] described the use of optical filters on a rigid transparent platform and used a video camera to record changes in motion. Hutton and Drabble [11] were probably the first to describe a quantitative method by using a force plate that subjects could step on.

With the rapid advancement in computer technology, many types of transducers have been developed with the ability to convert the pressure data to graphic display and analysis that can pinpoint areas of high pressure under the foot. A number of effective systems have been developed using these transducers to measure plantar foot pressure. The development of microprocessors started the technology for in-shoe foot pressure measurements.

F-Scan is a system that was developed using a resistive type transducer. The system employs the use of a mat or an insole to measure static and dynamic plantar foot pressures. For the purpose of this paper, the insole system is referred to as F-Scan and the method that uses the mat is referred to as F-Mat.

The F-Scan system

The F-Scan is a complete pressure sensing system consisting of both hardware and software components. The hardware collects data while the software allows visualisation of the data in real time or saved for later analysis.

The hardware component used for collection of the plantar pressures data can be either the F-Mat or in-shoe F-Scan. Both modalities are composed of resistive t sensors that continuously sample the data up to 165 times per second as the patient walks, runs or jumps. The F-Mat allows the patient to walk freely but has less resolution power compared to the in-shoe system. On the other hand, the in-shoe system requires the patient to be hooked up to a cable, thus limiting walking distance.

The F-Scan software is compatible with Microsoft Windows 95™/98™. In addition, a colour monitor and graphics card compatible with Microsoft Windows 95™/98™ are also required to view the data presented. The menu is user friendly and the system is easy to use and master. Detailed instructions can be found in the users' manual [12].

Application

The F-Scan system has been widely used to measure plantar foot pressures in many studies involving diabetic feet. In a study measuring in-shoe pressures in 51 patients with diabetes, the F-Scan system was found to be generally reliable for measurements of high pressure and peak pressure [13]. The F-Scan has proven to be an indispensable tool in evaluating ulceration risk in the neuropathic foot, determining the efficacy of the methods used to offload high-pressure areas, as well as delineating the changes in peak pressures and gait pattern following partial foot amputations.

A multi-centre prospective study involving 248 patients with diabetes examined the sensitivity, specificity and positive predictive value of basic screening techniques to predict foot ulceration. Risk factors evaluated included neuropathy disability score, vibration perception threshold, Semmes-Weinstein monofilaments, joint mobility, peak plantar foot pressures measured using the F-Mat and vascular status. While neuropathy disability score was shown to have the best sensitivity in predicting foot ulceration, plantar foot pressures was shown to have the best specificity [14].

Using the F-Mat system, investigators were able to establish a threshold peak plantar foot pressure at which ulceration risk doubled. A study of 251 patients with diabetes determined that patients with foot pressures less than or equal to to 6kg/cm were twice as likely to ulcerate compared to patients lacking high foot pressures [15].

High plantar foot pressures were also confirmed as an important risk factor for ulceration, especially when coupled with neuropathy.

Plantar foot pressures have also been measured to determine if variations in distribution patterns of foot ulceration between neuroischemic and neuropathic diabetic feet are related to differences in pressure loading. Peak plantar pressures were measured under four areas of the foot using the F-Scan system; medial and lateral forefoot, hallux and heel. Interestingly enough, plantar pressures were shown to be generally higher in the neuroischemic group than in both neuropathic and control groups [16]. This finding may indicate that the process of ulcer formation in neuroischemic and neuropathic patients differs and warrants further investigation.

Since high plantar pressures have been implicated as risk factors for foot ulceration in people with diabetes, offloading of high pressure areas is critical to prevent ulceration. The differences in plantar pressures in patients with diabetes and people without diabetes walking in shoes and walking barefoot were studied using the F-Scan system [17]. Use of the F-Scan system allowed in-shoe measurement of plantar pressures as well as barefoot plantar pressure measurements during gait. The study revealed that in-shoe pressures from the diabetic group were significantly lower than barefoot plantar pressures in both the diabetic and non-diabetic groups. Furthermore, it was found that diabetic shoes provided higher pressure reduction compared to shoes of the control group.

Orthotics may be useful in offloading high pressure areas of the foot. The F-Scan system was used to study the effectiveness of custom orthotics in distribution of plantar pressures in patients with a pronated foot type [18]. The F-Scan system was used to compare the total contact area under the foot between each patient with and without the orthotic device. It was concluded that the custom orthotics increased total contact area and thereby effectively reduced plantar pressures. The F-Scan has also proven useful in analysing the efficacy of various orthotic materials in pressure redistribution. Plastizote, cork and plastic orthoses all have the potential of relieving foot pressures; however, in doing so, may increase pressure in other areas of the foot [19].

Amputations are common following diabetic foot infections and ulceration. The F-Scan has been useful in determining peak pressures following amputation as well as delineating gait changes. Following big toe amputations in 11 diabetic patients, changes in peak plantar pressures were evaluated with the use of the F-scan [20]. There was found to be a significant increase in pressure under the first metatarsal head, lesser metatarsal heads, and lesser toes following a big toe amputation.

The F-Scan was also employed to compare the pattern of gait following midfoot amputations as well as ankle disarticulation amputations [21]. The F-Scan results revealed decreased propulsion magnitude in the midfoot amputees that may explain the increased metabolic costs associated with midfoot amputations as compared to ankle disarticulation amputations.

Conclusion

The F-Scan system with its in-shoe insole and F-Mat measuring devices has been used in a variety of studies involving patients with diabetes. It has been shown to be effective in identifying patients with high plantar foot pressure who are at risk of foot ulceration. It is also reliable in designing shoes and orthotics for diabetic patients to offload high pressure areas and is vital in assessing pressure redistribution and gait changes following amputation. The system is easy to use and also provides reliable quantitative and qualitative measurements.

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Editors' footnote

This paper describes only one type of system available to measure plantar foot pressures. Two other systems to note are Novel (Pedar and EMED) and the RS scan. Further information on these devices and plantar pressures can be found on the following websites:

- *F-Scan <www.tekscan.com>*
- *Novel <www.novel.de>*
- *RS scan <www.rsscan.com>*
- *Foot pressure special interest group<www.figroup.com>.*

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