Chapter

Assessment of Diabetic Foot

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Abstract

Diabetic Foot Complications are the main reason for hospitalization and amputation in people with diabetes. Globally ~435 million people have diabetes, with ~83–148 million of those estimated to develop foot ulcers in their lifetime. It is estimated that 16.8 million YLDs resulted from diabetic foot complications. Once an ulcer has developed, there is an increased risk of wound progression that may lead to amputation (~85% cases). In every 30 seconds, one lower limb amputation in diabetes patients occurs world-wide. The average cost for each amputation is over $70,000. American Podiatric Medical Association says that diabetic foot complications can be prevented by periodical Assessment of foot, which include visual inspection of bare foot; deformities, neurovascular abnormalities of foot and assessment of footwear. Relevant assessment and proactive foot care can reduce the burden of diabetic foot disease which will increase quality of life and reduce health care costs.

Keywords: diabetic foot ulcer, assessment, diabetic peripheral neuropathy, quality of life, prevention

1. Introduction

One of the most devastating consequences of diabetes mellitus is Diabetic Foot Disease (DFD) which represents a significant global burden for individuals and healthcare systems. It includes osseous degeneration, ulceration, and infection of the diabetic person's foot. [1]. These are associated with neurologic abnormalities, various degrees of peripheral arterial disease, and metabolic complications of diabetes in the lower limb [2]. The signs of diabetic foot are changes in skin tone, skin temperature, swelling of the foot or ankle, discomfort in the legs, open blisters on the feet that are difficult to heal or are draining, corns or calluses, dry skin fissures, particularly around the heel, and odd or persistent foot odors are all symptoms to observe. [3].

Diabetic foot symptoms vary from person to person and can depend on the particular problem the person is suffering at that moment. Symptoms include loss of sensation, numbness and tingling, blisters and other painless injuries, skin irritation and temperature changes, red streaks, injuries with or without discharge, painful tingling, and stains on socks. However, a person may also experience some of the following symptoms such as fever, feeling very sick, chills, uncontrollable blood sugar, shaking, shock, redness [4].

The first published diabetes-specific classification system, the Meggitt-Wagner system, is a simple system consisting of only six grades (0–5, 0 means intact skin), the first three is related to depth [5]. It's actually easy to use and may explain its popularity despite known limitations. For the sake of explanation, Peripheral Arterial Disease (PAD) and Infectious Diseases are not considered individually for superficial lesions and there is no mention of neuropathy. PAD is considered gangrene only at a later stage. Therefore, in clinical practice, the score is most often 2 or 3. This means that it is not accurate enough to isolate most lesions. Although its inaccuracies appear to be inadequate for research protocols, a systematic review of continuous wound healing by the International Working Group on Diabetic Foot shows that large works Meggitts - Wagner grade indicates the classification the patient population. Some other scales are used these are University of Texas wound classification system (UT), SAD system, the wound ischemia and foot infection classification (WIFI).

2. Pathophysiology

Diabetic peripheral neuropathy (loss of sensation) occurs typically 8–12 years after the onset of type 2 diabetes and is a tolerant factor for the development of ulcers. Diabetic peripheral neuropathy is a disorder of normal nerve activity throughout the body and can alter autonomic, motor, and sensory function [6]. Hyperglycemic conditions increase the production of several enzymes such as aldose reductase and sorbitol dehydrogenase. These enzymes convert glucose into sorbitol and fructose. The accumulation of these sugar products interferes with the synthesis of myo-inositol in nerve cells and impairs nerve conduction. In addition, hyperglycemic-induced microangiopathy results in reversible metabolic, motor and sensory nerve, immunological and ischemic damage leads to the autonomic nervous system dysfunction. It provokes low peripheral sensation and compensates for fine vasomotor control of pedal circulation and innervation of the small foot muscles. If the nerve is damaged, there is a risk of minor injuries, and when it is unnoticed an ulcer develops. [7].

The microcirculation of the skin is controlled by the autonomic nervous system, when disturbed in Diabetes causes dryness and cracking of the skin, making it more susceptible to infections. These changes can help spread gangrene, ulcers, and loss of limbs [8, 9]. Hyperglycemia causes endothelial cell dysfunction, and smooth cell abnormalities in peripheral dysfunction include altered endothelial cell proliferation, basal membrane thickening, decreased nitrogen monoxide synthesis, increased blood density, altered microvascular tone, and blood flow. Clinically the case may have signs of vascular insufficiency such as claudication, night pain or rest pain, absent peripheral pulses, thinning of the skin, loss of limb hair, etc. [6].

3. Importance of assessment

Foot disease affects almost 6% of diabetics and is associated with infections, ulcers, or destruction of foot tissue. Most ulcers can be prevented with proper foot care and screening of foot risk factors at risk of complications [9–11]. Uncontrolled diabetes contributes to the development of neuropathy and peripheral arterial disease through complex metabolic pathways. Loss of sensation due to peripheral neuropathy, ischemia due to peripheral arterial disease, or a combination thereof can cause foot ulcers. Thorough foot examination is important for early detection of the disease. Screening

for peripheral neuropathy and peripheral arterial disease helps identify patients at risk for foot ulcers. Assess the patient's general condition for signs of toxicity or sepsis, such as circulation or breathing, with or without malaise, poor appearance, abnormal behavior, and fever. At each follow-up schedule, examine feet for ulcers/gangrene. The purpose of screening is to identify patients who have lost foot protection [12, 13].

To identify diabetic patients at risk of ulcers, foot examinations are needed, including nervous and vascular system, skin disorders, and foot structure. According to age and length of diabetes, diabetic peripheral neuropathy, itself that affects up to 50% of diabetics and it is the most ubiquitous and crippling consequence of Diabetes mellitus. Peripheral senses (small and large nerve fibers) and motor nerves are affected by this condition, which is marked by significant axonal degeneration and segmental demyelination. [14–16].

4. Neurological assessment of diabetic foot

The clinical assessment of diabetic foot ulcer is currently subjective and limited, hampering effective diagnosis, treatment and prevention. Population-based studies report that the annual incidence of foot ulcers in diabetics is estimated to have DFU throughout their lives [17–19]. Once onset, despite treatment, foot ulcers may take weeks or months to heal, or may not heal at all. In addition, DFU is repeated frequently. Approximately 40% of patients will relapse within 1 year and 60% of patients will relapse within 3 years. The DFU not only reduces an individual's quality of life, but also has significant economic and social implications in the form of increased hospitalization rates, cost of care, and reduced patient mobility [20].

Most guidelines recommend 10 g of monofilament to assess neuropathy in diabetic patients. This test can be combined with another test to screen for neuropathy. Biothesiometer or graduated tuning fork (Rydel Seiffer) to determine the vibration perception threshold [21, 22]. The Modified Neuropathy Disorder Score (NDS) tests (**Table 1**) different sensory modalities of the foot and ankle - (i) vibration perception (using a 128 Hz sound fork), (ii) temperature perception (warm/cold), (iii). Pain (sharp/dull) and (iv) ankle jerk reflex- score range is 0 to 10, 0 for intact sensation and 10 for complete numbness with DPN. The Vibration Perception Threshold (VPT) is a semi-quantitative measure of sensory perception, usually placed at the tip of the toe and measured with a neuro or biothesiometer. VPT displays 0–50 volt readings, where 50 volt indicates complete numbness of DPN. Severe DPNs are usually stratified by VPTs with a modified NDS score of 6 or higher (or) of 25 volts or higher [22–25].

Inadequate foot protection due to nerve injury (neuropathy) does not result in compensatory mechanisms for painful stimuli such as dragging/gait changes to redistribute foot pressure. Continued inflammation results in enzymatic autolysis with tissue destruction and ulcers. The main goal of DFU clinical practice is to prevent the formation of ulcers through early detection and intervention. This reflects the challenges and medical costs associated with effective treatment after the onset of an ulcer. Regular foot evaluation and training are recommended for people with diabetes. This process is usually stratified by the risk of developing an ulcer. Current risk assessments are clinical and subjective, assessing the presence of callus as a surrogate marker for neuropathy, foot malformations, and high sole load, and for medium-risk or high-risk individual therapeutic footwear is recommended [26, 27].

Clinical evaluation tools require special training of clinical examiners to make accurate assessments based on patient outcomes. This assessment helps to efficiently

Neuropathy Disability Score (NDS)			
		Right	Left
Vibration perception threshold 128 Hz tuning fork; apex of big toe; trial pair = vibrating, nonvibrating (hit the wrong end of the tuning fork); normal = can distinguish vibrating / not vibrating	Subject sitting, eyes closed, legs outstretched: demonstrate on clavicle or dorsum of hand; in each case repeat three pairs of trials (mix up stimulus order within trial pair, in each case maintain stimulus 2 seconds); in each case ask "do you feel vibration / cold / sharp now or now?"; abnormal is at least two of three trials wrong or "cannot tell" normal = 0 abnormal = 1		
Temperature perception Rest Tip-Therm rod on dorsum of foot, trial pair = plastic end ("not cold"), metal end ("cold"); normal = can distinguish cold / not cold			
Pin-prick Apply Neurotip on proximal big toe just enough to deform skin; trial pair = sharp end, blunt end; normal = can distinguish sharp / not sharp			
Achilles reflex Kneeling on a chair, upright holding back of chair; stretch tendon to ankle neutral first; reinforcement – hook fingers together and pull when asked	present = 0 present with reinforcement = 1 absent = 2		
NDS Total out of 10			

Table 1.
NDS.

identify patients at risk and monitor whether they need intervention. The Assessment should also be based on an assessment of diabetic foot ulcer and risk of amputation, healing of diabetic foot ulcer, and assessment of diabetic foot ulcer infection [28]. Outcome measures for assessing diabetic neuropathy such as Utah Early Neuropathy Scale (UNES), for Ulcer risk (Queensland high-risk foot form or QHRFF); Diabetic foot ulcer assessment, scoring and amputation risk (Perfusion, Extent, Depth, Infection and Sensory scale or PEDIS); Site, Ischemia, Neuropathy, Bacterial infection and Depth assessment (SINBAD); Diabetic foot ulcer measurement (Leg Ulcer Measurement Tool LUMT) have been shown to be effective and valid.

An advanced home assessment tool for monitoring the feet of diabetics is desirable, and measuring the skin temperature of these feet is a promising modality. Temperature assessment is based on the idea that skin heat as a predictor of diabetic foot ulcer [29].

5. Vascular assessment of diabetic foot

Anatomical arterial disease can result in a more severe kind of perfusion deficit in patients with Diabetes and it is due to the paucity of collateral vessels and also the

influence of physiological factors like arteriolar shunting and neuropathy associated with Diabetes [30]. A complete physical examination should be carried out in any patient with Diabetic foot ulceration, particularly, a detailed medical history and assessment of peripheral pulses – however, clinical examination alone cannot reliably assess the severity of perfusion deficit [31]. In order to perform a detailed assessment of the peripheral artery and its perfusion, more tests are indeed necessary.

Commonly used imaging techniques like Duplex ultrasound and Angiography allow only the assessment of the morphological distribution of Peripheral artery disease and also provide some information on the global perfusion deficit. Patients with Ischaemic foot ulceration have compartmental perfusion deficit, in which the degree of perfusion at the actual area of tissue loss cannot be identified. Therefore, assessment of foot perfusion in a patient with diabetic foot ulcer should also include the regional tissue perfusion deficit [30].

5.1 Assessment of disease severity

The patients with diabetic foot ulceration should be evaluated for the presence of Peripheral artery disease during the time of presentation and they have to be managed in a multi-disciplinary setting [32–34]. The assessment of disease severity can be carried out using Ankle brachial pressure index, Toe pressures and Pulse volume recordings.

5.1.1 Ankle brachial pressure index

Doppler measure Ankle brachial pressure index is most commonly used to screen the presence of Peripheral artery disease. However, Ankle brachial pressure index and other routinely performed non – invasive bedside tests otherwise useful in the assessment of Peripheral artery disease may be unreliable in patients with Diabetes [35]. Ankle brachial pressure index score of <0.9 is indicative of impaired blood flow; however the finding of a normal Ankle brachial pressure index in a person with diabetes is not reliable – increased arterial stiffness may reduce distal flow [36] and medial arterial calcification, resulting in incompressible vessels which may in turn causes falsely elevated pressures.

5.1.2 Toe pressures

Toe pressure and toe arm pressure index (TBI) may be a more useful measure of perfusion due to the characteristic sparing of the foot arteries from vascular disease in diabetics [30]. Toe pressure can be effectively measured using photoplethysmography (which detects pulsating flow to generate pulse wave waveforms) or laser Doppler (which detects wavelength changes when a laser hits blood cells).

5.1.3 Pulse volume recordings

Pulse rate records are also used to identify the presence of arterial disease. The amount of pulse wave corresponds to the cardiac cycle-rapid upstrokes and sharp spikes occur during systole, gradually slopes down during diastole, followed by reflective waves (dicrotic notches). In the presence of arterial disease, the waveform flattens and the pulse width widens. When pulse volume recordings are used in lower limbs, the changes in the waveform denotes the general location of significant disease,

whereas it assesses the total blood flow through the area and cannot give accurate information regarding the exact location of the disease [30]. Pulse volume recordings are useful in patients with Diabetes who have falsely elevated Ankle brachial pressure index because of calcified vessels [37], as the effect of calcification on the waveform is usually distinguishable from that because of obstructive arterial disease.

5.2 Assessment of morphological distribution

The anatomical distribution of the disease in patients with diabetic foot ulcer is to determine if revascularization is necessary and, if necessary, which method (intravascular or open surgery) is appropriate and useful. The main challenge in imaging the arterial tree of diabetics is the characteristically complex anatomical distribution of the disease. [30].

5.2.1 Duplex ultrasound

Color duplex ultrasound is the first imaging technique used to examine patients with peripheral arterial disease. The patients with Diabetes have a diffuse and distal arterial disease; detailed imaging studies along with duplex ultrasound need to be used for pre – operative investigation while planning for revascularization.

5.2.2 Angiography

Detailed morphological information can be provided by Angiography. Traditional digital subtraction angiography (DSA) is the gold standard method cannot fully identify patent distal vessels for which Magnetic resonance angiography (MRA) can be used [30].

5.3 Assessment of regional tissue perfusion

Assessment of local tissue perfusion is more useful in understanding the perfusion deficit at the exact area and also helps to estimate the healing tendency. Diabetic patients need this assessment, as global perfusion assessment measures usually do not reflect the regional deficit, due to poor collateralization found in them.

5.3.1 Transcutaneous oxygen tension ($Tcpo_2$)

Transcutaneous oxygen tension ($TcPO_2$) measurement is an established method of evaluating the cutaneous perfusion and it is also more sensitive in detecting Peripheral artery disease than Ankle brachial pressure index in patients with Diabetes [38]. $TcPO_2$ measures the transfer of oxygen molecules to the skin surface and a reduction in transcutaneous oxygen tension is commonly in patients with Peripheral artery disease [39]. $TcPO_2$ values may be paradoxically increased in patients with Diabetes due to arteriolar shunting in the microcirculation and is also affected by the metabolic demands of the tissue being assessed.

5.3.2 Skin perfusion pressure

Skin perfusion pressure has been used as a successful measure to assess the lower limb ischaemia severity and also analyses the chances of wound healing and thereby helps in selecting the appropriate level of amputation [40, 41].

5.3.3 Fluorescence angiography

It commonly uses Indocyanine green dye (ICG) for measuring the fluorescence intensity at various areas of the involved limb, thereby allows a semi – quantitative measurement of regional perfusion and identifies the superficial collaterals in patients with arterial occlusions [30]. It is also used in patients with critical limb ischaemia to provide more rapid and quantitative information about foot perfusion [42].

5.3.4 Laser Doppler techniques

Laser Doppler flowmetry is used to measure the local microcirculatory blood perfusion by using a beam of Laser light which is partially absorbed when it hits the tissue being evaluated, to a depth of up to 1 mm. The change in wavelength like magnitude and frequency can be converted into a measurement thereby representing the relative perfusion than absolute values. It has been used to identify poor perfusion in lower extremity ulcers [43].

Hence a comprehensive assessment of foot perfusion in Diabetes patients should therefore include anatomical assessments of structural arterial disease combined with evaluation of regional tissue perfusion. The most commonly available techniques also have certain limitations while relating to the complexity of Diabetes. Novel techniques which are meant to assess muscle and deep tissue perfusion are under the process of development, which are more likely to be used widely in the near future.

6. Biomechanical assessment of diabetic foot

Peripheral neuropathy causes changes in foot function as well as in structure (due to prominent Metatarsal heads), dryness of the skin which in turn can end up in excessive callus formation [44–46]. An important risk factor for the development of Diabetic foot ulceration is high plantar foot pressure [47, 48]. In patients with Diabetes, limited joint mobility in the ankle and foot complex also had suggested to increase plantar pressure [49, 50] and also to be related with foot ulceration [51, 52]. The prevalence of limited joint mobility varies between 49% and 58% in Type I Diabetes patients and between 45% and 52% in Type II Diabetes patients [53, 54].

Most of the Diabetic foot ulcers occur in the forefoot, mainly under the metatarsal heads and under the digits (hallux). When the metatarsal head makes contact with the ground, it usually contacts at a single point because the inferior aspect of each metatarsal head is usually round.

The main structure responsible for dissipating the pressure from the lowest point of the metatarsal heads, to the sides of the metatarsal heads, then to the intermetatarsal spaces and to the points which are proximal and distal to the metatarsal heads is Metatarsal fat pad [55]. Patients with diabetes with or without neuropathy generally have decreased thickness in the metatarsal fat pads. The thinner the metatarsal fat pad, the higher the risk of developing Diabetic foot ulcers [56, 57]. The easiest way to measure fat pad thickness under the metatarsal heads is by using Ultrasound [58].

A softer metatarsal fat pad increases the shock absorption of the forefoot while hitting the ground, whereas a stiffer metatarsal fat pad decreases shock absorption thereby greater energy gets imparted to the soft tissues while landing on the forefoot [59]. The stiffer metatarsal fat pad prevents the load from being distributed medially

and laterally from the deepest point of the metatarsal head. Therefore, more stress is applied to the soft tissue pad just below the metatarsophalangeal head, and less stress is applied to the part of the fat pad between the metatarsophalangeal heads. [60].

In Diabetes, the collagen in the plantar fat pad not only stiffness but also the collagen tissues throughout the body stiffen. This stiffening of the entire collagen tissue causes all ligaments to become stiff and all joints to lose mobility [61]. Thus it can be a serious issue for most phase of the Gait cycle.

During the stance phase of gait, the hind foot begins with a slight inversion and then eversion. The forefoot first lands on the fifth metatarsal head, then each metatarsal lands from lateral to medial. At the end of the stance phase, the hind foot is slightly everted and the fore foot is slightly inverted. If a diabetic presents a normal amount of hind foot eversion during contact, the forefoot may be difficult to compensate by inverting at the mid tarsal joints. It can increase the pressure under the first and second metatarsal heads. On the other hand, if the forefoot cannot be fully inverted to pronate the sub talar joint, the pressure under the 4th and 5th metatarsal heads will increase. Coronal and sagittal movements are also reduced in all metatarsals with stiffer collagen tissue. [62].

The glycation of the Achilles tendon increases the tendon's thickness and stiffness [63, 64]. It in turn causes several changes in the diabetic foot, including earlier forefoot loading at contact as well as an increased load on the forefoot during the stance phase of gait [65, 66]. The thickening of plantar fascia happens along with the thickening of the Achilles tendon [67]. The thickened Achilles tendon decreases the effect of windlass mechanism of the foot, which further decreases the dorsiflexion of the digits, decreased time in the propulsive period of gait and a decrease in the supination of the hind foot during foot propulsion [68, 69]. Diabetic neuropathy has a greater adverse effect on the foot. Tissue glycation is the predicting factor of other diabetic complications including neuropathy. The joint mobility of the subtalar joint is significantly reduced in the ulcerated foot than the contra lateral non ulcerated foot in Diabetic neuropathic patients [47]. Hence, combination of neuropathy and trauma results in breakdown of tissue. Increased plantar pressure can be contributed to the alterations in the foot shape, presence of callus and limited joint mobility.

Kinematic analysis was performed on the knees and ankles using 3D SIMI REALITY MOTION SYSTEM GmbH, Germany, two Basler high-speed cameras (1394a/b, GigE, 100fps @ 1Megapixel). We used Kinetik I-Step software (Aetrex, USA) and Wintrack Dynamic Scan Floor Mat (Medicapteure software, France, USA). Significant differences in kinematic and kinematic variables such as toe-off knee angle, static knee speed, heel strike, mid-stance and toe-off, static knee acceleration, heel strike and mid-stance, and ankle joint angle, Mid stance, static ankle speed, heel strike and mid stance, static ankle acceleration, heel strike, mid stance and toe off, walk cycle duration, maximum average sole pressure and maximum ankle pressure Was recognized. Therefore biomechanical analysis is an important tool and can be used for early screening and prediction of altered kinematic and kinetics in diabetes mellitus [70].

7. Conclusion

Patients may not receive the podiatry follow-up necessary to identify warning signs of recurrence and provide appropriate management. To guide preventive strategies, it is necessary to fully understand the factors that predict the recurrence of

ulcers. The strongest predictor of diabetic foot ulcer is the previous foot ulcer. A study of patients with healed foot ulcers has shown that early signs of skin damage such as heavy calluses, blisters, and bleeding are one of the strongest predictors of ulcer recurrence. If these pre-ulcer lesions are recognized early, their treatment can probably prevent the recurrence of many ulcers [21].

Low-risk individuals may progress to medium-risk or high-risk and should continue their foot examinations annually. More frequent follow-up is recommended for medium-risk or high-risk patients. Patients with foot malformations or patients diagnosed with peripheral neuropathy or peripheral arterial disease at baseline. Introducing prophylactic foot care services for basic nail and skin care including, wound resection of callus, for patients with callus and deformed toe nail. Timely referrals to foot protection services to manage risk factors for diabetics prevent infection, gangrene, amputation, or death, reducing hospitalization and costs [22].

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Conflict of interest

The authors declare no conflict of interest.

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