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Assessment of Diabetic Foot through the Developmental Stages of Lower Limb Abnormalities Using Ultrasound

Suresh K.S. and Sukesh Kumar A.

Abstract

A diabetic foot is one of the most serious complications of diabetes mellitus. This causes large number of lower leg amputations worldwide. Usually this disease is getting diagnosed in a very later stage. Ankle-arm index, diastolic blood pressure, fasting plasma glucose, hemoglobin A1C, high blood pressure, medial arterial calcification, nerve conduction velocity, peripheral vascular disease, systolic blood pressure, transcutaneous oxygen tension, etc. are some of the major indicators of a diabetic foot. Among these peripheral arterial abnormalities and neuropathy are the most dominant visible factors. Detection and monitoring of diabetic foot help to demonstrate the feet at risk of ulceration positively. This study reveals the various assessment methodologies of lower limb abnormalities leading to diabetic foot using ultrasound. Ultrasound is being used in various cases related to diabetic foot, from the identification of systolic pressure for the ankle brachial pressure index to the velocity analysis of hemodynamic studies. The study analyses the lower limb abnormalities and extracts the features of diabetic foot from the velocity spectrum of ultrasound Doppler scan.

Keywords: diabetic foot, diabetic neuropathy, peripheral arterial disease, diabetes mellitus, early detection, Doppler ultrasound

1. Introduction

Diabetes is a growing global epidemic of the current century. This occurs either when the pancreas does not produce enough insulin or when the body cannot effectively use the produced insulin. According to the International Diabetes Federation, it is estimated that presently 387 million people are being affected by diabetes, and this may increase to 592 million in the coming 20 years [1]. In addition to this, 316 million people are at high risk with impaired glucose tolerance, and a projection shows that in 2035, the count of high-risk people will attain more than 1 billion. According to the recent estimation of the World Health Organization (WHO), diabetes is being suffered by 9% among adults aged 18+ years. Approximately 1.5 million deaths were directly caused by diabetes in 2012, and 80% of this occurred in low- and middle-income countries. Diabetes is estimated to be the seventh leading cause of death in 2030 by the WHO [2]. The statistics of the International Diabetes

Federation reveals that in India there are nearly 65 million diabetes cases [3]. The associated complications of diabetes have also been increased in proportionate to the high rate of diabetes-affected persons.

Among the variety of complications related to diabetes, a diabetic foot stands one of the most threatening one. If the foot exhibits any pathology because of diabetes mellitus or any complications due to the long-term suffering of diabetes. The study reveals various types lower limb abnormalities and analyses the features of diabetic foot from the velocity spectrum of ultrasound Doppler scan.

2. Diabetic foot disease

In diabetic cases, foot problem may develop as a part of damaging nerve and blood vessels. This may cause the infection and ulceration of the leg and finally come to the level of amputation. This is one of the dangerous conditions. Foot diseases are the most probable causes of hospital admissions in the case of diabetes. Considering the total patients suffering from diabetes mellitus, diabetic foot disease probably occurs 15–25% of them. Among the diabetic foot patients, 85% of the cases precede to partial lower leg amputation. Individuals with diabetes are 25 times bound to lose a leg than individuals without the condition.

More than 70% of leg amputations throughout the world are due to diabetes [4]. Every year, around 1 million diabetic people lose a leg because of their diseased condition. The diabetic foot also causes major economic consequences for the patients, their families and the entire society. The International Working Group on the Diabetic Foot estimated that a lower limb is lost to diabetes somewhere in the world in every 20 seconds [5].

Ankle-arm index, diastolic blood pressure, plasma glucose, hemoglobin A1C, high blood pressure, medial arterial calcification, peripheral vascular disease, systolic blood pressure and transcutaneous oxygen tension are the major identified indicators of diabetic foot. Comparing the overall visible symptoms of diabetic foot, peripheral arterial disease and diabetic neuropathy seem to be the most important threatening factors [6, 7].

3. Lower limb abnormalities leading to diabetic foot

Peripheral arterial disease (PAD) is of great clinical significance in diabetic patients. Some of them have high risk of subsequent myocardial infarction or stroke, irrespective of the presence or absence of symptoms of PAD. Lack of proper treatment can lead to functional disability and limb loss. So, regular screening of PAD is very important as a part of proper management to minimize the impact of comorbidities on the diseased person.

The human nervous system is also very much affected with diabetes. The peripheral nerves, the nerves that go to the arms, hands, legs and feet, may get damaged with persistent high glucose level. Usually, the diabetic peripheral neuropathy arises in different places of the human body but very prominently affects the sensations of the toes and feet [8]. This abnormal sensation may lead a feeling of being pricked with pins, throbbing and numbness with sharp pain and tingling and burning sensations.

The risk for foot ulcers and amputation is increased by diabetic peripheral neuropathy. People who are suffering from diabetic peripheral neuropathy mostly do not notice minor cuts, sores or blisters in their foot and toes. This is

because of the loss of sensation in connection with the damage of the nerves in the corresponding areas. Neuropathy affects the sensory, motor and autonomic systems of the human body. The untreated wounds become easily infected and may lead to gangrene, which finally require amputation in that area. If this is diagnosed in the early stages, it is a major opportunity to ameliorate symptoms and prevent the development of the major clinical neuropathic endpoints of the lower limb [9] such as chronic painful foot, the insensate foot, the Charcot foot and the neuropathic ulcer. It is important that physicians and other healthcare providers understand that diabetic neuropathy can occur with no pain or with an insensate foot or may present with pain in the form of dysesthesias and paresthesias.

4. Role of ultrasound

The ultrasound wave is one of the safest and easiest modes of medical diagnosis. This modality of medical imaging helps to identify internal body structures in a noninvasive manner. This has been achieved by computerized analysis of reflected ultrasound waves. Usually frequencies of 1–30 MHz are being used for a diagnostic purpose. The resolution of the image depends on the type of wave used, higher resolution with shorter wavelengths, and the wavelength is inversely proportional to the frequency [10]. However, the use of high frequencies is limited by their greater attenuation in the tissue and thus shorter depth of penetration. The frequencies 2–10 MHz are used for vascular studies.

Doppler ultrasound provides the basis for noninvasive and objective measurements of the spectrum and serially monitors the velocity of flow in the arteries. This Doppler ultrasound has very high potential for monitoring blood flow velocity as it is reliable and noninvasive and provides real-time result. In Doppler analysis, the ultrasound beam has the sum of the instantaneous contributions of each particle crossing that beam. A human observer can interpret it because such mixtures of signals are sorted according to the frequency and weighted with the intensity in the cochlea. The signal needs to endure a similar process of sorting and weighting for visual interpretation. For this process, the Doppler signal has to be translated into the frequency domain, and it is done in real-time computation with fast Fourier transform of successive segments of the Doppler signal. The stationarity of the blood flow may be assumed by shortening the segments.

The power spectrum generated for each segment indicates the velocity distribution of the particles within that beam during the time interval in accordance with the width of the segment. The inverse of the time interval indicates the spectral resolution. Power spectrum point relates to a frequency interval showing a velocity range, whereas the height of each point signifies the power or the quantity of particles in that particular velocity range.

5. Vascular examination

The ankle-brachial pressure index (ABPI) is one of the most common techniques being used for initial diagnosis of foot disease. This is a particular ratio of the recorded highest pressure at the ankle for that leg to the highest brachial pressure measured for both arms. The normal range of ABPI comes below 1. When ABPI < 0.92, it is an indication of arterial disease. The value of ABPI between 0.5 and 0.9 may be connected with claudication, and for these symptoms the patient

should be referred for further examination. If ABPI rate is below 0.5, it is a symptom of severe arterial disease, and this may be associated with gangrene, ischemic ulceration or rest pain, and urgent referral is required for a vascular opinion. The pressure at the ankle and brachial artery is determined with the ultrasound. Pressure is measured by blood pressure apparatus, but the auscultation is determined by Doppler ultrasound [11]. The state of peripheral circulation can be easily identified with the examination of the legs. Peripheral arterial examination using ultrasound gives a lot of indications related to diabetic foot [12]. Stenosis or occlusions in the segments of the peripheral arteries can be detected in patients who have suspected arterial occlusive disease. The clinical indications such as claudication, ischemic tissue loss, rest pain and suspected arterial embolization may exist in these patients. The sites can be monitored by various percutaneous interventions, including angioplasty, thrombolysis, atherectomy, and stent placements. The examination can also be done by the evaluation of suspected vascular and perivascular abnormalities, such as aneurysms, pseudoaneurysms and arteriovenous fistulas. The presence of significant arterial abnormalities can be identified and confirmed by imaging modalities [13].

One of the indications for peripheral venous ultrasound examinations is the evaluation of possible venous thromboembolic disease or venous obstruction in symptomatic or high-risk asymptomatic individuals. Assessments of venous insufficiency, reflux and varicosities are some of the other indications. The examination is also being done by the evaluation of veins before venous access. Follow-up for patients with known venous thrombosis near the anticipated end of anticoagulation is used in the presence of residual venous thrombosis [14].

The arterial occlusive disease is identified by the evaluation of the arterial segments, such as lower extremity, common femoral artery, proximal superficial femoral artery, mid superficial femoral artery, distal superficial femoral artery, popliteal artery, etc. A focused or limited examination may be appropriate in certain clinical situations. At a minimum, an angle-corrected spectral Doppler waveform with velocity measurements should be obtained from any of the above sites. If clinically appropriate, imaging of the iliac, deep femoral, tibioperoneal and dorsalis pedis arteries can be performed [15].

Figure 1 shows the evaluation of a patient having pain in the left lower limb. The spectral color Doppler ultrasound of the venous system has been done in this case. The color Doppler images analyze the study of veins such as popliteal, left femoral and peroneal veins and anterior-posterior tibial veins.
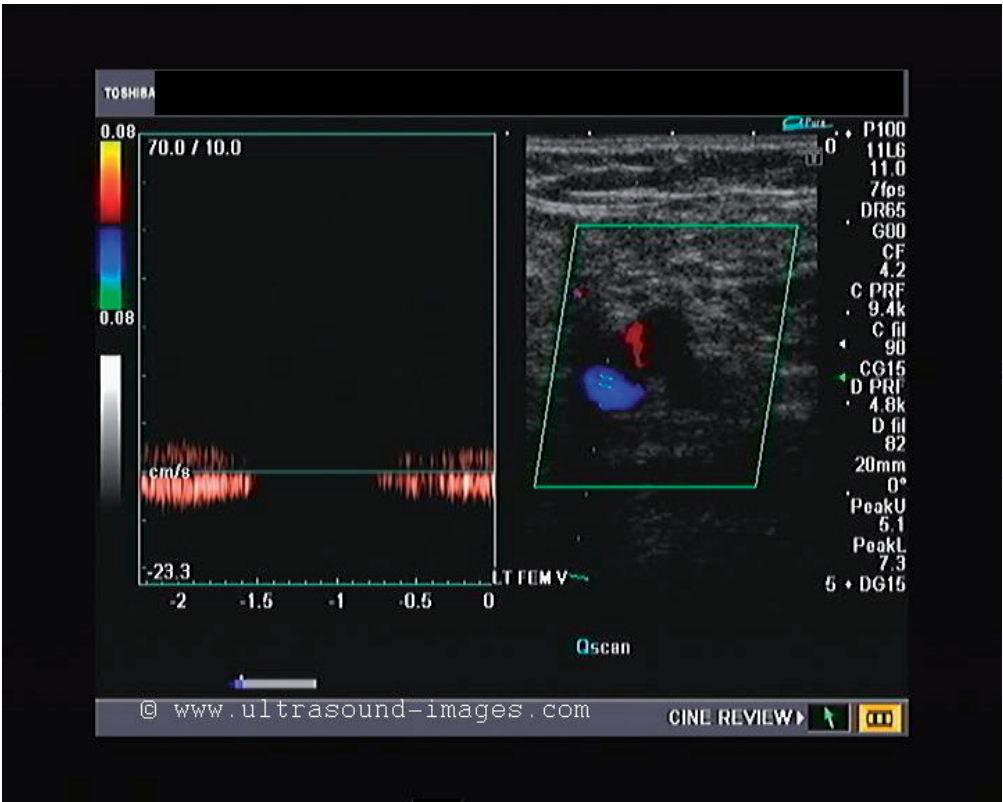
Usually complete visualization of the veins of the leg is very difficult. Normally it is being done by imaging the upper third and distal third of the anterior, posterior tibial and peroneal veins.

Figure 2 is an ultrasound color Doppler image of the right lower limb showing early indications of diabetic arteriopathy. This is also called as diabetic vasculopathy. The corresponding characteristic features in the color Doppler ultrasound image are:
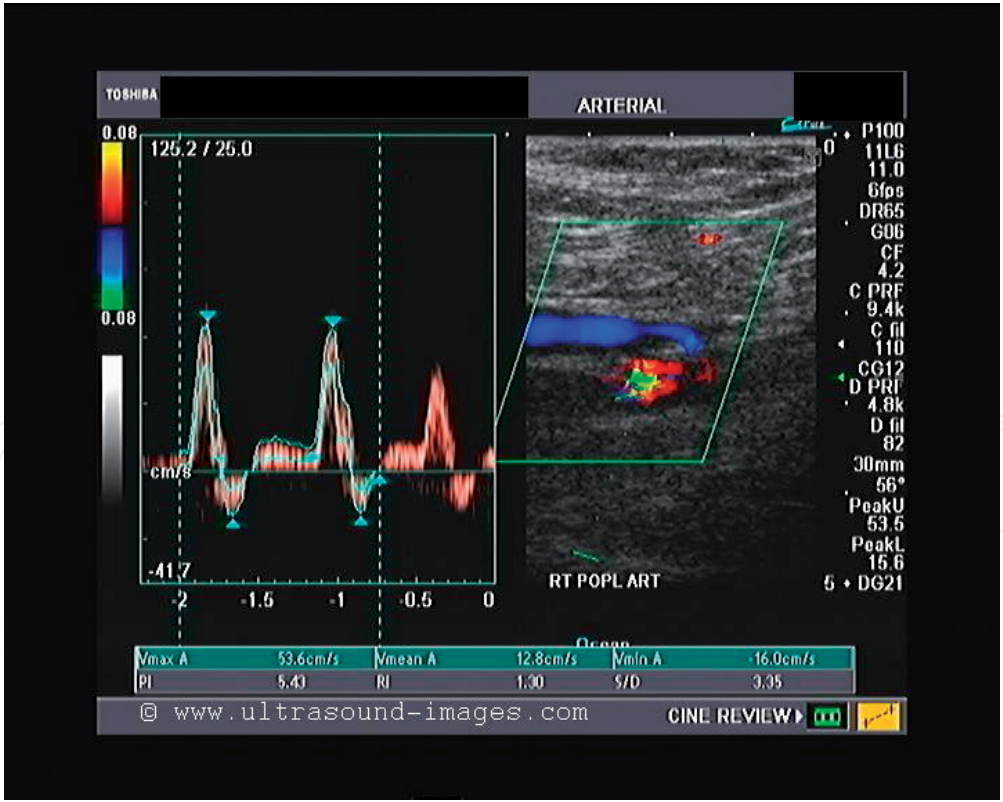
- In the arterial waveform, there is a spectral broadening from the popliteal artery downwards.

- Slight decrease in the peak systolic velocity below the popliteal artery.

- Early changes of loss of the triphasic spectral waveform are present in the peroneal artery.

The changes mentioned above are typically seen in early diabetic arteriopathy indicating mild stenosis in a diffuse fashion below the popliteal artery.

Figure 1.
Venous Doppler of the lower limb: normal case (presented with permission from Dr. Joe's ultrasound).

Figure 2.
Mild diabetic arteriopathy of the lower limb (presented with permission from Dr. Joe's ultrasound scan, Cochin).

In Doppler waveform analysis, normal pulsed wave is a clearly defined tracing with narrow Doppler spectrum. In normal cases, the peripheral artery waveform is triphasic. When blood flow becomes turbulent at bifurcations and luminal narrowing, it causes spectral broadening of Doppler waveform.

5

6. Velocity spectrum

The Doppler arterial waveform images can be analyzed to provide information about blood flow in or out of the gut and related along with the other physiological measurements.

The velocity information perceived from a single location in the blood vessel is displayed in the form of frequency shift-time plot in the case of real-time spectral Doppler analysis. The time along the horizontal axis and frequency shift or identified velocity along the vertical axis will be displayed.

The clinical information attained from the maximum Doppler shift correspond to a spatial maximum in the velocity field. Systematic analysis can be done with spectral Doppler ultrasound velocimetry, an analysis of the spectrum of frequencies by which the Doppler signal is constituted [16].

The Doppler frequency shift happens with backscattering of millions of red blood cells. The resultant shifted signal is the summation of such multiple Doppler frequency shifts.

The processing of Doppler signal is accomplished through various steps. After the initial reception, the next step is amplification. It is demodulated, and the characteristic parameters of flow are identified by further spectral processing methods. The Doppler shift frequency is proportional to the velocity of the blood flow. The power in a particular frequency band of the Doppler spectrum is proportional to the volume of blood, under ideal uniform sampling conditions.

As the blood moving with velocities create frequencies in the particular band, the power Doppler spectrum has the same shape as the velocity distribution plot for the flow in the vessel. The deviation in the shape of the Doppler power spectrum as a function of time is normally denoted in the form of sonograms.

7. Conclusion

The frequency level and patterns of lower limb arterial insufficiency in diabetic patients can be evaluated by Doppler-based techniques. The most prominent case of diabetic foot is the development of vasculopathic changes leading to peripheral vascular insufficiency. This can be detected by analyzing velocity spectrum of blood flow in the lower limb. Angle-corrected spectral Doppler waveforms should be effectively utilized for the recognition procedure. Precise evaluation has to be attained with further analysis.

Acknowledgements

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References

[1] International Diabetes Federation, Annual Report; 2014

[2] World Health Organization. Diabetes Programme. 2015. Available from: http://www.who.int/diabetes/en/

[3] International Diabetes Federation. IDF Diabetes Atlas. 6th ed; 2013. Available from: http://www.idf.org/ diabetesatlas

[4] International Diabetes Federation. Diabetes and Foot Care Time to Act; 2005

[5] International Working Group on the Diabetic Foot. Guidance docsuments. 2015. Available from: http://iwgdf.org/ guidelines/

[6] Reiber GE, Lemaster JW. Epidemiology and economic impact of foot ulcers and amputations in people with diabetes. In: Levin and O'Neal's the Diabetic Foot. 7th ed. USA: Mosby Elsevier PA; 2008. pp. 3-22

[7] Zimny S, Dessel F, Ehren M, Pfohl M. Helmut Schatz "early detection of microcirculatory impairment in diabetic patients with foot at risk". Diabetes Care. 2001;**24**:1810-1814

[8] Suresh KS, Sukesh Kumar A. An investigation for early stage diagnosis of diabetic foot. International Journal of Enhanced Research In Science Technology & Engineering. 2016;**5**(12):40-43

[9] Suresh KS, Sukesh Kumar A. Clinical need of a diabetic foot infection detector. In: National Conference on Advances in Computational Intelligence & Communication Technologies. 2016. pp. 125-128

[10] World Health Organization. Manual of Diagnostic Ultrasound; 2011

[11] Suresh KS, Sukesh Kumar A. An integrated model for early detection and monitoring of diabetic foot. In: Proceedings of International Conference on Modelling and Simulation, Association for the Advancement of Modelling and Simulation Techniques in Enterprises. 2017

[12] Bessonov N, Sequeira A, Simakov S, Vassilevskii Y, Volpert V. Methods of blood flow modelling. Mathematical Modelling of Natural Phenomena. 2016;**11**(1):1-25

[13] Lingegowda D, Moorthy S, Sreekumar KP, Kannan RR. Imaging in diabetic ischemic foot. International Journal of Diabetes in Developing Countries. 2010;**30**(4):179-184

[14] AIUM Practice Guide Line for the Performance of Peripheral Venous Ultrasound Examinations. American Institute of Ultrasound in Medicine; 2010

[15] AIUM Practice Guide Line for the Performance of Peripheral Arterial Ultrasound Examinations Using Color and Spectral Doppler Imaging. American Institute of Ultrasound in Medicine; 2010

[16] Gerhard-Herman M, Gardin JM, Jaff M, Mohler E, Roman M, Naqvi TZ. Guidelines for noninvasive vascular laboratory testing: A report from the American Society of Echocardiography and the Society of Vascular Medicine and Biology. Journal of the American Society of Echocardiography. 2006;**19**(8):955-972