A CLOUD SYSTEM UTILIZED FOR DIABETIC FOOT MANAGEMENT

MINGYU HU¹, QUTING HUANG¹, BO XU¹, WUYONG CHEN¹, JIANXIN WU², JIN ZHOU^{1,2*}

¹*Sichuan University, National Engineering Laboratory for Clean Technology of Leather Manufacture; Chengdu 610065, P. R. China*

²*Science Lab, Zhejiang Red Dragonfly Footwear Co., LTD., Zhejiang Province, Wenzhou 325100, P. R. China, *corresponding author email: zj_scu@scu.edu.cn*

Diabetic foot is one of the major chronic complications of diabetes mellitus, where foot infection, deep tissue destruction due to local nerve abnormalities and peripheral vascular lesions in the distal extremity of the lower limbs are usually found. Those feet lesions are also assumed as main reasons to cause the ulceration, amputees, or even the death of patients. Appropriate intervention is helpful in the daily care of diabetic feet. However, current approaches only considered one or several foot conditions through routine inspection, such as diabetic peripheral index (DPI) or MICHIGAN test etc., an overall evaluation for the diabetic feet were lacking. Therefore, the purpose of this study was aimed to establish a cloud system for diabetic feet management, where we can quantify the diabetic feet according to an algorithm designed to overall evaluation. Those data were transferred into digital format and saved in the cloud platform, where remote accessing is available. In our system, we included examination of peripheral neuropathy, foot deformities and plantar pressure of the patient and this system could be applied for both the management of diabetic feet and used for early warning in order to prevent feet ulcerations.

Keywords: diabetes foot management system; algorithm to evaluate the risk of ulceration; diabetic peripheral neuropathy.

INTRODUCTION

Diabetic foot (DF) is one of the major chronic complications of diabetes mellitus. Appropriate intervention is helpful in daily care of diabetic feet, which will not only help patients avoid amputates, but also alleviate a lot of financial burden (Boulton *et al.*, 2005). However, proper prevention of DF requires accurate evaluation. Key factors have been reported that lead to DF and they were Diabetic Peripheral Neuropathy (DPN), Peripheral Vascular Lesions (PVD), Foot Infection, Ulcers and Deep tissue destruction (van Netten *et al.*, 2016). Accordingly, methods are established for assessment, such as Neuropathy Impairment Score in the Lower Limbs (NIS-LL), Michigan Neuropathy Screening Instrument (MNSI), Michigan Diabetic Neuropathy Score (MDNS), Neurological Disability Score (NDS), Neurological Symptom Score (NSS) and Toronto Clinical Scoring System (TCSS) (Bril, 1999; Ohnishi *et al.*, 1999; Bril and Perkins, 2002; Dias *et al.*, 2015; Nisansala and Wimalasekera, 2015; Wei, 2018). Physical protocols such as Semmes-Weinstein Monofilament Examination (SWME), Tuning Fork, and Vibration Perception Thresholds (VPT) are also widely used due to their low cost of tools (Lavery and Armstrong, 2012; Bagherzadeh Cham *et al.*, 2016). Other clinical detective devices liking Quantitative Sensory, Electromyogram and Electrocardiograph, Ergograph, Force Plate, and Plantar Pressure Plate are also used for DPN's evaluate (Lavery *et al.*, 2002; Turgut *et al.*, 2009; Kuhn *et al.*, 2017). Moreover, in terms of quantification of PVD, Color Doppler Flow Imaging, Digital Subtraction Angiography, Transcutaneous Oxygen Pressure and other medical equipment are adopted (Goebel *et al.*, 1995; Chen *et al.*, 2008; Reichelta *et al.*, 2009; Gastroenterology *et al.*, 2010). Unfortunately, some protocols are too expensive for either medical institutions or patients in their DF assessment.

Current literatures were widely reported concerning on the DF assessment. Meggitt and Wagner had first divided the DF into six level marked as 0 to 5 to help doctor to determine whether patients need amputation (Wagner, 1981). To add the infection and ischemia symptoms. After that Lavery *et al.* (Armstrong, 1996) created the Texas method on the basis of Wagner, that can be used to predict the healing time of patients. Macfarlane had also put forward a new method to describe DF in 1999, S(AD)SAD classification (Macfarlane and Jeffcoate, 1999). This method enables the ordinary to distinguish the pathological state of patients and was more suitable for statistic research than Texas method. In 2004, a DEPA scoring system which Unprecedented contained the score, grade, predict prognosis, treatment of patients was developed by Foot Hospital of Jordan University (Younes and Albsoul, 2004). At the same, the International Working Group of the DF (IWGDF) launched the PEDIS classification system (Schaper, 2004), which was objective and accurate in description of infection and ischemia, but no description of the size of ulcers. Then in the year 2005, Strauss and Akenov used Strauss classification to differentiate the wound of foot (Strauss and Aksenov, 2005). Next year, Beckert from German provided the DUSS (Diabetic Ulcer Severity Score) (Beckert *et al.*, 2006), which was the first to apart the ulcerations from the location in toe or foot, single or multiple ulcers. Furthermore, new classifications such as SINBAD Scoring system, MAID Scoring system and SEWSS Scoring system were separately improved from S(AD)SAD classification, DUSS system and PEDIS system (Schaper, 2004; Ince *et al.*, 2008; Beckert *et al.*, 2009). All of the approaches had a different degree of improvement. But now no classification system could perfectly evaluate diabetic foot. Thus, doctors need to choose the method considering the balance of advantages and limitation. Previous studies only evaluated the DB in a single level, which cause the incomplete in the assessment process; moreover, results of those approaches could not be compared since no standards were regulated. Those two reasons make it hard to comprehensively judge the DB.

Therefore, the purpose of this study was aimed to establish a cloud system for diabetic feet management, where we can quantify the diabetic feet according to algorithm designed to overall evaluation for those inspection data which were transferred into digital format and saved in the cloud platform.

METHODS

Subjects

In our system, patients with DB were recruited by the guidance of doctors in the hospital. Doctors would introduce the system to patients and give advice for patients about the acquisition frequency.

Data Collection of DF

DPN, foot deformities and plantar pressure of the patient were detected as the input data of the system. Their processes were as follows:

In the DPN detection process, we first chose the Michigan patient's self-rating scale to obtain the subjective score of patients. This scale includes twelve questions that reflects the symptoms of DPN of the foot. Then 10 g nylon wire stimulation, 128Hz tuning fork and percussion hammer conditioned reflex were adopted (Malik *et al.*, 2003). Toe and thumb of foot were simulated by the Nylon wire and fork respectively,

and the hammer was used to test knee reflex. In the self-test report, each question equals 1 point, and the feeling of physical test can be calculated as: 0 for normal feel, 1 for disappeared feel and 0.5 for the weakened feel. Then, the score of self-test and physical test were uploaded to cloud.

Foot deformities were evaluated using Static three-dimensional foot scanner (LSF350-AM, 3DOEsolution Int., China). Through three laser cameras, the transverse section of the foot is scanned at the frequency of 50Hz from three vertical angles. The data collected will be fitted into the three-dimensional entity by the software, and the static foot image will be obtained. In the scanning process, patients stand statically with their both feet separate naturally. Data of this section can be used to identify the foot deformities. Strephenopodia or arch collapse, mallet or overlapping toes and hallux valgus. The number of deformities would be counted.

Plantar pressure was tested by Footscan Pressure Plate System (one-meter plate, RSscan Int., Belgium), with scanning frequency of 250Hz (Birch *et al.*, 1998). Distribution of the plantar pressure and the peak pressure can be recorded during the statistic stand and walking period of our test. Plantar was divided into six parts as follows: interior forefoot, medial forefoot, lateral forefoot, midfoot, lateral and external heel. Pressure, impulse and contact area were counted and normalized to relative values by their weight and total contact area. Then the above factors were compared with a criterion, which was made calculated of a group of healthy participants (Liu *et al.*, 2017).

Point of DPN, level of foot deformities and pressure distribution of patients were uploaded to our cloud server. Then the collection step had already finished.

Data Processing

All the data in the cloud system were visualized and the expert could read the report of patients. The self-test point and total physical point will both directly send to doctor. Number of deformities also be distinguished as: Mild (no or one deformities), Moderate (two deformities), Severe (multiple deformities). As for plantar plate force, pressure that in, at the edge and beyond the criterion would be marked as green, yellow and red color on the report of cloud. Experts would give a diagnosis based on the report.

Report of a Case

Report of one participant was shown in Figure 1, patients could follow the advice of doctor to make better prevention of his foot.

Figure 1. A case of the report. Left part of the figure shown the information of the patients, and the right part contains the point of DPN and number of foot deformities.

Mid part of picture is the plantar pressure of the patients, green, yellow and red are separately resemble normal, warning and severe degrees of pressure value. Doctor advise were given at bottom of the picture, in this case, doctor suggested the patients to enhance the nursing of his foot.

RESULTS AND DISCUSSION

System was put into used on 24 January 2017, 1168 patients have registered and uploaded their information to the system, few of them keep the collection as a habit. Data and diagnostic report can provide the information of patients, and the longitudinal detection of patients could provide more information in evaluating the pathological stage in DF.

Advantages of the system are the data could be upload to the cloud system. This feature enables the doctors the ability to achieve access the information and remote diagnosis. Since the low cost of detection equipment, detection point could be sited to remote countryside, patients lived far from city can also uploaded their information to doctor immediately. Longitudinal data acquisition enables patients have their individual electronic medical records and the service of obtaining long-term tracking data.

As for the data we collect, since DPN can be detected in a low-cost way, and some other factors can be detected by inspection. Longitudinal followed up need to set up a number of detection site, and we focused on the big sample of the patients. So, through the comprehensive consideration of the cost and our goals, we detect the DPN, foot deformities and plantar pressure of the patient for medical examination of diabetic feet

and those data were saved in the cloud server. In current stage, we fulfilled the process of cloud system establishment and more and more inspection data from diabetic patients were adding to this system. Our system would be applied for early warning and strategy making of clinical intervention for diabetic feet, in order to avoid the occurrence of foot ulcerations.

CONCLUSION

In our system, key factors of patients could be recorded, doctors could evaluate condition of the patients remotely. Longitudinal followed up could be easily achieved in our system. More and more people participant and record their information of DF in our cloud system. Now this system enables doctors to achieve remote diagnose.

REFERENCES

- Armstrong, D.G. (1996), "The University of Texas Diabetic Foot Classification System", *Ostomy/wound Management*, 42(8), 60-1.
- Bagherzadeh Cham, M. *et al.* (2016), "Reliability of Semmes-Weinstein Monofilaments and tuning fork on pressure and vibration sensation measurement in diabetic patients", *Iranian Journal of Rehabilitation*.
- Beckert, S. *et al.* (2006), "A new wound-based severity score for diabetic foot ulcers: A prospective analysis of 1,000 patients", *Diabetes Care*, 29(5), 988.
- Beckert, S. *et al.* (2009), "M.A.I.D.: A prognostic score estimating probability of healing in chronic lower extremity wounds", *Annals of Surgery*, 249(4), 677, <https://doi.org/10.1097/SLA.0b013e31819eda06>.
- Birch, I. *et al.* (1998), "Foot pressure measurement and diabetes: Where we are now?", *Diabetic Foot*, 1, 28-32.
- Boulton, A.J. *et al.* (1987), "The natural history of foot pressure abnormalities in neuropathic diabetic subjects", *Diabetes Research*, 5(2), 73, [https://doi.org/10.1016/S0140-6736\(05\)67698-2](https://doi.org/10.1016/S0140-6736(05)67698-2).
- Boulton, A.J. *et al.* (2005), "The global burden of diabetic foot disease", *The Lancet*, 366(9498), 1719-1724.
- Bril, V. (1999), "NIS-LL: The Primary Measurement Scale for Clinical Trial Endpoints in Diabetic Peripheral Neuropathy", *European Neurology*, 41(Suppl.1), 8-13.
- Bril, V. and Perkins, B.A. (2002), "Validation of the Toronto Clinical Scoring System for Diabetic Polyneuropathy", *Diabetes Care*, 25(11), 2048, <https://doi.org/10.1159/000052074>.
- Chen, X. *et al.* (2008), "Danshen Tablet on TNF- α , hs-CRP and 6-MWT in Patients with Diabetes and Heart Failure", *Chinese Journal of Integrative Medicine on Cardio-Cerebrovascular Disease*, 1.
- Dias, L.S. *et al.* (2015), "Sensitivity and specificity of neuropathy diabetes score, neuropathy symptoms score, diabetic neuropathy score and esthesiometry compared with the gold standards Michigan neuropathy screening instrument (MNSI) and Beck depression inventory (BDI)", *Diabetology & Metabolic Syndrome*, 7(S1), 1-2, <https://doi.org/10.1186/1758-5996-7-S1-A199>.
- Goebel, W. *et al.* (1995), "Color Doppler imaging: a new technique to assess orbital blood flow in patients with diabetic retinopathy", *Invest Ophthalmol Vis Sci*, 36(5), 864-70.
- Gonzalez, J.A. (1989), "Artificial intelligence: expert systems", *Isla Transactions*, 28(1), 1.
- Ince, P. *et al.* (2008), "Use of the SINBAD Classification System and Score in Comparing Outcome of Foot Ulcer Management on Three Continents", *Diabetes Care*, 31(5), 964, <https://doi.org/10.2337/dc07-2367>.
- Kuhn, B. *et al.* (2017), "(438) Quantitative sensory testing (QST) and diabetes risk: are abnormalities in small diameter afferents present in healthy persons at high risk for diabetes?", *Journal of Pain*, 18(4), S83, <https://doi.org/10.1016/j.jpain.2017.02.288>.
- Lavery, L.A. and Armstrong, D.G. (2012), *Clinical Examination and Risk Classification of the Diabetic Foot*, Humana Press.
- Lavery, L.A. *et al.* (2002), "Ankle equinus deformity and its relationship to high plantar pressure in a large population with diabetes mellitus", *Journal of the American Podiatric Medical Association*, 92(9), 479-82, <https://doi.org/10.7547/87507315-92-9-479>.
- Liu, J. *et al.* (2017), "Classification of Diabetic Feet in Terms of Risk of Ulceration", *Leather and Footwear Journal*, 17(3), 129-134, <https://doi.org/10.24264/lfj.17.3.2>.
- Macfarlane, R.M. and Jeffcoate, W.J. (1999), "Classification of diabetic foot ulcers: The S(AD) SAD system", *The Diabetic Foot*, 2(4), 123-131.
- Malik, R.A. *et al.* (2003), "Corneal confocal microscopy: a non-invasive surrogate of nerve fibre damage and repair in diabetic patients", *Diabetologia*, 46(5), 683-688, <https://doi.org/10.1007/s00125-003-1086-8>.

<https://doi.org/10.24264/icams-2018.X.3>

- Nisansala, M.W.N. and Wimalasekera, S.W. (2015), "Usefulness of Michigan Neuropathy Screening Instrument (MNSI) in diagnosis of diabetic neuropathy in a Sri Lankan diabetic clinic", *Proceedings of the Scientific Sessions of the Faculty of Medical Sciences*, University of Sri Jayewardenepura, Nugegoda.
- Ohnishi, A. *et al.* (1999), "[A family of hereditary motor and sensory neuropathy type 1B showing a marked difference of neurological disability score among affected family members]", *Journal of Uoeh*, 21(2), 149, <https://doi.org/10.7888/juoch.21.149>.
- Reichel, A. *et al.* (2009), "Chronic thromboembolic pulmonary hypertension: Evaluation with 64-detector row CT versus digital subtraction angiography", *European Journal of Radiology*, 71(1), 49-54, <https://doi.org/10.1016/j.ejrad.2008.03.016>.
- Schaper, N.C. (2004), "Diabetic foot ulcer classification system for research purposes: a progress report on criteria for including patients in research studies", *Diabetes/metabolism Research & Reviews*, 20, S90, <https://doi.org/10.1002/dmrr.464>.
- Strauss, M.B. and Aksenov, I.V. (2005), "Evaluation of diabetic wound classifications and a new wound score", *Clin Orthop Relat Res*, 439(439), 79-86, <https://doi.org/10.1097/01.blo.0000182393.31978.c3>.
- Turgut, N.L. *et al.* (2009), "Comparative Neurophysiological Study for the Diagnosis of Mild Polyneuropathy in Patients with Diabetes Mellitus and Glucose Intolerance", *International Journal of Neuroscience*, 116(6), 745-759, <https://doi.org/10.1080/00207450600675340>.
- van Netten, J.J. *et al.* (2016), "Prevention of foot ulcers in the at-risk patient with diabetes: a systematic review", *Diabetes/Metabolism Research and Reviews*, 32, 84-98, <https://doi.org/10.1002/dmrr.2701>.
- Wagner, F.W., Jr. (1981), "The dysvascular foot: a system for diagnosis and treatment", *Foot & Ankle*, 2(2), 64, <https://doi.org/10.1177/107110078100200202>.
- Wei, Y. (2018), "The analysis of the symptom score, neurological function and quality of life of the patients with cerebral infarction treated by fuqi tongluo decoction", *Contemporary Medicine*.
- Younes, N.A. and Albsoul, A.M. (2004), "The DEPA scoring system and its correlation with the healing rate of diabetic foot ulcers", *Journal of Foot & Ankle Surgery*, 43(4), 209-213, <https://doi.org/10.1053/j.jfas.2004.05.003>.