Review on the Vibration Perception Threshold to Early Detect Diabetes Mellitus

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Abstract. The total population of diabetic patients increases from 4.7 % to 8.5 % in the adult population worldwide in only three decades. In Malaysia, more than 3 million of total population have been inflicted with diabetes. Vibration Perception Threshold is a non-invasive technique that can measure loss of sensation due to diabetic peripheral neuropathy. The threshold mainly depends on the frequency of vibration, the area of contact, the applied force, and the location of measurement. This paper will review on the factors influencing the vibration perception threshold and recent studies on the use of VPT to detect diabetes.

Keywords: diabetes mellitus; vibration perception threshold (VPT); diabetes neuropathy

1. Introduction
In three decades from 1980 to 2014, the world population diagnosed with diabetes increased from 108 million to 422 million people, rising nearly half percent from 4.7 % to 8.5 % [1]. One of the main factors for the increase was due to the change in daily diet, which led to overweight, apart from other equivalence factors such as the lack of diabetes knowledge [2]. The prevalence of diabetes has risen faster in low- and middle-income countries than in high-income countries [3]. In 2012 alone, about 1.5 million people died due to diabetes, more than other diseases such as cardiovascular disease [4].

Diabetes is a disease caused when the level of glucose in blood is too high. When glucose stays in a body for too long, it will lead to other diseases. Thus, patient with diabetes will have to monitor their diet so that the glucose level can be controlled [1]. The most common types of diabetes are Type 1, Type 2, and Gestational diabetes [1]. Over three million cases had been reported in Malaysia or nearly 17 % of population in Malaysia has been diagnosed by diabetes [5].

Generally, method for diagnosing diabetes can be divided into two distinct approaches which are invasive and non-invasive. Insistent screening for diabetes is crucial for early detection and consequently increases benefits which can be gained from quick intervention [6]. A study suggests the necessity for early intervention and treatment of diabetes through routine screening to prevent severe complication in later stages [7].

Diabetes is conventionally screened by assessing the level of glucose and haemoglobin in blood, coupled with urine analysis and symptoms scores [8]. Three notable blood glucose tests namely random
plasma glucose (RPG), fasting plasma glucose (FPG) and oral glucose tolerance (OGT). RPG is the most convenient since it does not require fasting in advance compared to the other two. The blood glucose tests will require blood sample to be taken from the patient and analysed for its glucose content before being rated accordingly. Although the process can be quick, the method is invasive.

Several researchers have reviewed the implementation of haemoglobin AIC test as a screening test for Type 2 Diabetes [9]. Several drawbacks associated with the former glucose tests were eliminated through the introduction of hba1c test [10]. Once blood sample is taken, it will be analysed to measure the amount of sugar attached to the red blood cell. Fasting is not required and long-term hyperglycaemia is better reflected [11]. However, this test is still an invasive test.

Recent advancement in device technology has enabled researchers to propose another method for diagnosing diabetes. Quantitative Sensory Testing (QST) is a non-invasive technique developed to detect early and precisely, changes in sensory nerve fiber that often linked to the diabetic peripheral neuropathy (DPN). Diabetic peripheral neuropathy is a progressive manifestation of diabetes with length-dependent and significant damage of nerve fibers. Diabetic neuropathy is now thought to be the most common form of peripheral neuropathy. Loss of sensation due to DPN can be assessed through various testing methods including current peripheral threshold (CPT), thermal peripheral threshold (TPT), and vibration perception threshold (VPT). QST has been criticized by many as being highly subjective [12].

Over years of having diabetes, diabetic patients will have loss of sensation of vibration, leading to a vibration perception threshold (VPT) that is greater than healthy patient. Symptoms of diabetes are commonly unnoticed at the early stages, thus conventional diabetes tests are deferred [13]. At the time of diagnosis, patient commonly exhibits the presence of diabetics neuropathy, significantly that the clinically inception of the diseases ensued at an earlier period, presumably several years preceding diagnosis [citation needed]. Hence, the method of VPT has potential to be further studied to early detect diabetes. This paper will review on the factors influencing the vibration perception threshold to diagnose diabetes mellitus.

2. Vibration Perception Threshold

A study proposes that the decrease of vibratory sensation could be an indicator of DPN, which is one of the most common complication associated with the diabetes [14]. It has been showed that VPT can be used as a sensitive measure of DPN in Type 1 Diabetes, and came up with a comparable conclusion for Type 2 diabetes subjects [15]. Several researchers agreed that the diagnosis peripheral sensory neuropathy can be confirm with the VPT [16]. Developed a novel method with high accuracy and reliability in monitoring [17]. Higher VPT value of patient suffering from foot ulceration compared to those without were recorded by using a Biothesiometer [18].

The measuring of vibration perception threshold starts with the subject or patient is exposed to a vibration. The vibration magnitude increases gradually and when the subject perceives the vibration, he or she will give feedback by pressing the feedback button. Once the feedback button is being pressed, vibration magnitude will decrease gradually then when subject does not perceive the vibration, he or she will release the feedback button. The procedure repeats until a threshold is acquired based on an algorithm. The complete procedures of measuring VPT is published in the International Standard ISO13091.

A vibrotactile perception threshold device contains a vibrator, a force cell, an accelerometer, a feedback button, a probe, and a set of data acquisition device (Figure 1). The vibrator generates vibration either random or sinusoidal at certain frequency of vibration. Force cell is used to indicate whether appropriate force is applied onto the probe based on the international standard. The probe is designed so that it will provide optimized vibration exposure depending on the contact area and contact force. The accelerometer measures vibration exposed to the subject.
3. Factors Influencing the Vibration Perception Threshold

The International Standard ISO13091 suggests three frequencies of vibration exposure as stimulus for the assessment of VPT which are 4, 31.5, and 125 Hz. Studies have shown that the prominent factors influencing the dynamic response of the human hand or finger are the contact area and contact force [19, 20], apart from the location of measurement, vibration magnitude and posture of the hand. The International Standard ISO13091 also proposes guidance for the applied force and contact area. Vibrotactile is lowest of the fingertip when compared to volar forearm, large toe and heel [21]. For this review, the effects of frequency of vibration, applied force and the area of contact on VPT measured at the fingertip (due to the lowest vibrotactile threshold found by previous study) are further discussed especially since both are the prominent factors that can influence the VPT.

Mechanoreceptors in the hand are responsible for the perception of vibration. The identification of mechanoreceptors that reflect to the vibration perception at certain frequencies has been the purpose of many fundamental studies conducted previously. Fast adapting (FA) units include those sensitive at frequencies between 5 Hz to 50 Hz (FAI) and frequencies above 50 Hz (FAII). A study conducted early 1990 ranging from 16 Hz to 800 Hz, has found that the vibration perception threshold increases as the frequency of vibration is increased [22]. A curve inflection was found at 63 Hz -80 Hz which though to be due to the FAI units for frequencies 16 Hz and 31.5 Hz, and FAII units at 125 Hz, 250 Hz and 500 Hz [22].

The sensitivity threshold depends on the mechanoreceptor and sensory nerve fibres. Previous study has shown that the dynamic response of the hand at frequencies greater than the resonance increases with increasing contact force [23]. The increase in the dynamic response of the hand can lead to a lower threshold since the motion could be vibration perception threshold. Hence, a study conducted previously has found similar observation when applied force is increased, although the reduction of threshold is only found to be significant at frequencies greater than 125 Hz [24].

The area in contact with the hand influences the dynamic response of the hand [23]. Increasing the contact area will increase the sensation for which the amount of vibration transmitted to the finger will be larger than smaller contact area. However, it is not as direct as that. Low frequency threshold is expected to be lower with smaller contact area whilst high frequency threshold is expected to be lower
with larger contactor [21]. With surround condition, the vibrotactile threshold has been found to be lower than without surround condition at frequencies less than 63 Hz [22].

4. Diagnosing diabetes using VPT
The ability of the hand to feel vibration is determined by the mechanoreceptors responsible to detect the sensation exposed. Recent study has shown that the VPT can be a good method to detect Type 2 diabetes patients [25-29]. In a study that used a case-control comparison between diabetic patients and non-diabetic patients has shown that the prevalence of peripheral sensory neuropathy (PSN) screened by VPT is 24.5% in diabetic patients and 8.5% in non-diabetic patients with significant determinants of PSN by abnormal VPT were diabetes status, age, heart rate, second-hand smoking and body height in all the participants [26]. VPT used for early detection of neuropathy is highly sensitive and accurate when compared to gold standard NCV. However, the VPT can depend on the contact area and contact location [21] and should not be compared [30]. Increased VPT has been linked with diminished sensation in diabetes patients [25-28]. Diabetic patients with less than or equal to 5 years of diagnosis have significantly higher perception threshold compared to the healthy group subjects [31]. It was found that there is a positive correlation between the number of years suffering from diabetes and the degree of threshold shift [31]. VPT is a non-invasive method that has the potential to detect diabetes at early stage. A study conducted in 2004 has found that vibration perception threshold of Malaysians is consistent with reference data of the ISO13091-2 [32].

5. Conclusions
Vibration perception threshold technique has been used widely to early detect peripheral neuropathies. However, the assessment depends on factors such as the contact area, contact force, frequency of vibration and location of measurement. Early study on VPT to detect diabetes has shown a good result to characterise diabetic and non-diabetic patient. The recommendation by testing the different prominent parameter by build the VPT experimentally can test the best condition to detect diabetes mellitus.

Acknowledgments
The authors would like to be obliged to Universiti Putra Malaysia for providing laboratory facilities and financial assistance under project no. GP-IPM 9499300.

References
[1] Abdelhafiz, A. H., & Sinclair, A. J. (2018). Diabetes in the elderly Key points. Medicine, 1–4.
[2] Manivannan, M., Periyasamy, R., & Narayananmurthy, V. B. (2008). Vibration perception threshold and the law of mobility in diabetic mellitus patients, 3, 17–21.
[3] Rubio-Cabezas O, Hattersley AT, Njølstad PR, et al. ISPAD Clinical Practice Consensus Guidelines 2014. The diagnosis and management of monogenic diabetes in children and adolescents. Pediatric Diabetes.2014;15(suppl 20):47–64.
[4] Carmody D, Stoy J, Greeley SAW, Bell GI, Philipson, LH. A clinical guide to monogenic diabetes. In: Weiss RE, Refetoff S, eds. Genetic Diagnosis of Endocrine Disorders. 2nd ed. Philadelphia, PA: Elsevier; 2016:21–30.
[5] Chew, B., Lee, P., Cheong, A., & Ismail, M. (2016). Messages from the Malaysian Diabetes Registries on Diabetes Care in Malaysian public healthcare. Primary Care Diabetes, 10(5), 383–386.
[6] Kolber MR, Scrimshaw C. Family history of cardiovascular disease. Canadian Family Physician.2014;60(11):1016.
[7] American Diabetes Association. Classification and diagnosis of diabetes. Diabetes Care. 2018;41(suppl 1):S22–S24. [5] Shigley J E and Mischke C R 2006 Mechanical Engineering Design (New York, USA: McGraw-Hill)
[8] Huo X, Gao L, Guo L, et al. Risk of non-fatal cardiovascular diseases in early-onset versus late-onset type 2 diabetes in China: a cross-sectional study. The Lancet Diabetes & Endocrinology.
[9] Carmody D, Stoy J, Greeley SAW, Bell GI, Philipson, LH. A clinical guide to monogenic diabetes. In: Weiss RE, Refetoff S, eds. Genetic Diagnosis of Endocrine Disorders. 2nd ed. Philadelphia, PA: Elsevier; 2016:21–30.

[10] Pihoker C, Gilliam LK, Ellard S, et al. Prevalence, characteristics and clinical diagnosis of maturity onset diabetes of the young due to mutations in HNF1A, HNF4A, and glucokinase: results from the SEARCH for Diabetes in Youth. The Journal of Clinical Endocrinology and Metabolism. 2013;98(10):4055–4062.

[11] Martin, L. B., Hopkins, W. A., Mydlarz, L. D., & Rohr, J. R. (2010). The effects of anthropogenic global changes on immune functions and disease resistance, 1195, 129–148.

[12] Letourneau LR, Carmody D, Wroblewski K, et al. Diabetes presentation in infancy: high risk of diabetic ketoacidosis [published online August 4, 2017]. Diabetes Care. 2017:e1–e2.

[13] National Centers for Disease Control and Prevention. National diabetes statistics report, 2014. https://www.cdc.gov/diabetes/data/statistics/statistics-report.html. Accessed December 22, 2016.

[14] Leavitt, P. R., Fritz, S. C., Anderson, N. J., Baker, P. A., Blenckner, T., Bunting, L., … Werne, J. (2009). Paleolimnological evidence of the effects on lakes of energy and mass transfer from climate and humans, 54, 2330–2348.

[15] R Daud, S Maeda, Nnm Kameel, My Ripin, N Bakrun, Rm Zein, M Kido, And H Kiguchi. 2004. A Pilot Study of Reference Vibrotactile Perception Thresholds on the Fingertip Obtained with Malaysian Healthy People Using ISO 13091-1 Equipment. Industrial Health 42: 189-195.

[16] Bowling, B., & Phillips, C. (2007). Disproportionate and Discriminatory : Reviewing the Evidence on Police Stop and Search, 70, 936–961.

[17] Tucker, S., Bowen, W. D., Iverson, S. J., Blanchard, W., & Stenson, G. B. (2015). Sources of variation in diets of harp and hooded seals estimated from quantitative fatty acid signature analysis (QFASA), (July).

[18] Jude, E. B., Eleftheriadou, I., & Tentolouris, N. (2010). Review Article Peripheral arterial disease in diabetes — a review, 4-14.

[19] Rezali KAM and Griffin MJ (2017) Transmission of vibration through gloves: effects of contact area. Ergonomics, 60(1), 69-81

[20] Rezali KAM and Griffin MJ (2018) Transmission of vibration through gloves: effects of contact force. Ergonomics, 61(9), 1246-1258

[21] Morioka M and Griffin MJ (2008) Vibrotactile threshold at the fingertip, volar forearm, large toe, and heel. Somatosensory and Motor Research. 25 (2). 101-112.

[22] Harada N and Griffin MJ (1991) Factors influencing vibration sense threshold used to assess occupational exposures to hand transmitted vibration. British Journal of Industrial Medicine. 48, 185-192

[23] Bowling, B., & Phillips, C. (2007). Disproportionate and Discriminatory : Reviewing the Evidence on Police Stop and Search, 70, 936–961.

[24] Merlino, G., Valente, M., Serafini, A., & Gigli, G. L. (2007). Restless legs syndrome : diagnosis , epidemiology , classification and consequences.

[25] Shah A, and Shah D. 2 018. A Study to compare detection of peripheral neuropathy in type 2 diabetes using nerve conduction velocity and biothesiometry. Paripe - indian journal of research

[26] Yeboah K, Puplampu P, Boima V, Antwi D, Gyan B, and Amoah A. 2016. Peripheral sensory neuropathy in type 2 diabetes patients: A case control study in Accra, Ghana. Journal of Clinical and Translational Endocrinology. 5, 26-31

[27] Coppini D, Young P, Weng C, Macleod A, and Sönksen P. 1998. Outcome on diabetic foot complications in relation to clinical examination and quantitative sensory testing: A case-control study. Diabetic Medicine. 15(9) 765-771

[28] Manivannan M, Periyasamy R, Narayanamurthy V. 2009. Vibration perception threshold and the law of mobility in diabetic mellitus patients. Primary Care Diabetes. 3(1), 17-21

[29] Lee CC, Perkins BA, Kayaniyil S, Harris SB, Retnakaran R, Gerstein HC, Zinman BH, Anthony
J. 2015. Peripheral neuropathy and nerve dysfunction in individuals at high risk for type 2 diabetes: The PROMISE cohort. Diabetes Care 2015.

[30] A Sulistyo, SA Adam, KAM Rezali, and NAA Jalil. 2015. Vibration Perception Threshold for Early Diabetic Syndrome Detection. RCMME.

[31] Gu C, Griffin MJ. 2013. Spatial summation of vibrotactile sensations at the foot. Med Eng Phys 2013.

[32] E.H. Weber, De pulsu, resorptione, auditu et tactu, in: H.E. Ross, D.J. Murray (Eds.), E.H. Weber On the Tactile Senses, Taylor & Francis, Hove (UK), 1834.