

Original article

Bioimpedance phase angle analysis of foot skin in diabetic patients: An experimental case study

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Abstract

Objectives

Bioimpedance analysis has been recently reported to characterize tissue pathologies. One of the many diabetes complications is diabetic foot disease, whose early signs are manifested at microscope level in small foot nerves endings. The experimental case study has conceived from the starting point, as already reported results show, that foot nerves endings are affected by diabetes disease. The hypothesis was that a change of foot skin electrical properties might be expected in diabetic patients. Hence, the goal was focused on finding out distinctive bioimpedance behavior of foot skin in diabetic patients.

Methods

The experiment is based on measuring and analyzing bioimpedance samples of hallux skin of thirty non-diabetic and thirty diabetic participants. The measurement method was the two-electrode technique. A measurement procedure was proposed and applied with medical supervision of the experiment participants. Bioimpedance components data were statistically analyzed figuring out electrical behavior of diabetic hallux skin.

Results

According to the analysis between data results of diabetic and non-diabetic participants, a distinctive behavior in bioimpedance phase component was observed in the frequency range of 1–20 kHz. The bioimpedance samples of diabetic participants resulted in smaller group phase averages than the corresponding of non-diabetic participants.

Conclusions

A distinctive behavior of bioimpedance phase obtained from foot skin of diabetic participants was observed along the studied frequency range. According to the case study results, it is inferred that diabetes disease has some effect on electrical properties of foot skin, particularly in the group average of the bioimpedance phase angle measured on the hallux skin area of diabetic patients.

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1. Introduction

Diabetes is one of the main causes of worldwide human mortality and one leading cause of morbidities such as: blindness, renal failure, and non-traumatic amputations. Prolonged time having diabetes is associated with numerous complications, including: cerebrovascular, cardiovascular retinopathy, neuropathy, nephropathy and peripheral arterial diseases. A common complication in the lower extremities is the diabetic foot ulcer. It is estimated that 15% of patients with diabetes will develop

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a lower extremity ulcer during the course of the disease. The reported prevalence of foot ulcers for a variety of population ranges from 2% up to 10% [1,2]. Simple tests such as monofilament, tuning fork, ankle reflexes, determination of a vibration perception threshold, and pinprick sensation alone or in combination have been studied and have shown to be useful tools for identification of patients at risk of diabetes foot disease [3,4]. Most of the available literature is focused on the median nerve neuropathy at the carpal tunnel level [5] or the tibia nerve neuropathy at the tarsal tunnel level [6], being the median and tibia nerves the relatively longest ones of all peripheral nerves. With the rapid development of high frequency ultrasound technology, the very small nerves close to the nerve endings, such as the digital [7] and palmar cutaneous nerves [8], could be clearly monitored by high-resolution ultrasound.

The use of non-invasive techniques to characterize functional anomalies of biological tissues has been widely researched in last two decades. The use of bioelectrical impedance analysis (BIA) for determining human body pathologies is widely accepted as a safe, rapid and reliable technique. The BIA is a simple low-cost and non-invasive procedure used in evaluating body composition in clinical routine and in weight reduction programs [9,10]. The impedance imaginary component has been analyzed to figure out its capability of giving extra information compared with the real component [11]. The study in [12] established whether the whole body complex impedance at 50 kHz was sensitive to the presence of pitting edema localized on a patient's leg. A review of bioimpedance spectroscopy (BIS) and BIA methods for measuring body fluid volumes through impedance is presented in [13]. Several bioimpedance applications have been reported. A bioimpedance-based method for muscle function assessment is described in [14]. In [15] a new method for tissue impedance measuring is proposed. A bioimpedance-based comparison between hemodynamic profiles in transurethral resection is described in [16]. Identification of factors like adipocytokines is described in [17], such factors are closely related to absolute body fat weight, body fat ratio, and insulin resistance in patients with type 2 diabetes mellitus. A comparison between the distribution of impedance vectors measured in male patients with cancer, at different disease stages, with that from healthy men, matched in age and body mass index, is presented in [18].

Studies have shown that the early signs of diabetic foot are manifested in small nerve endings, but not in large digital nerves. According to the reports, the problems on nerve endings [19] and microcirculation [20] seem to be the causes of diabetic foot. Hence, foot nerves endings are affected by diabetes disease and consequently a change of electrical properties on foot skin might be expected. The experimental case study described in this paper was developed in order to figure out a characteristic electrical behavior of foot skin in patients with type 2 diabetes disease (non-insulin dependent). The research goal was focused on researching potential differences in the hallux bioimpedance behavior between non-diabetic and diabetic persons. The hallux is the human body part where skin damages due to diabetic foot disease are firstly manifested, mainly as microscopic ulcers [21]. The experiment is based on measuring

and analyzing bioimpedance samples of the hallux skin of thirty diabetic and thirty non-diabetic participants. All components of the obtained bioimpedance data were statistically analyzed in order to figure out the electrical behavior of hallux skin in diabetic participants. From all studied bioimpedance parameters a distinctive behavior between non-diabetic and diabetic participants was observed, particularly in the bioimpedance phase angle data for a frequency range of 1–20 kHz.

The bioimpedance measuring method is depicted in second section. In third section, experimentally obtained results are shown. The results discussion and conclusions of the experimental case study are presented in fourth and fifth sections, respectively.

2. Participants

The bioimpedance samples were measured in patients from two health care centres located in the city of Celaya, Gto., México. The first one is a public hospital named “Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado” (ISSSTE) and the second one is a private nursing home. All participants were informed about the study to be performed and all gave their informed consent for inclusion before their study participation. The total number of participants was sixty, classified in two groups: thirty participants without diabetes (ND group) and thirty participants with type 2 diabetes (D group). Each participant was individually identified by his group followed by a participant number. The non-diabetic participants were identified as: ND1, ND2, ..., ND30; and diabetic participants as: D1, D2, ..., D30.

The D group participants were eleven men and nineteen women. All D group participants had type 2 diabetes with a zero degree in Wagner classification [22]. The age range of D group participants was from 44 up to 79 years old, and the glycaemia level range was from 86 mg/dl up to 415 mg/dl. The glycaemia level was measured with a glucometer (Acc-check, mode perform) fifteen minutes before the bioimpedance measuring, which was done in a room with a temperature of $25 \pm 1^\circ\text{C}$.

The ND group was composed by eleven men and nineteen women, with age range from 40 up to 90 years old. In order to be included as a non-diabetic participant several restrictions were considered in the selection process. For instance no family history of diabetes, have not suffered any lower extremities trauma, and not having foot calluses. Besides, in order to make sure the absence of glucose level variations, typically presented in diabetic persons, a glycaemia level measurement was made for each participant.

3. Methods

3.1. Bioimpedance measurement

The block diagram of the bioimpedance measurement system is depicted in Fig. 1. All bioimpedance samples were obtained with same impedance meter (LCR HiTESTER 3532-50, HIOKI), through the bipolar method. Electrodes made of

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