A new method of analysis of standing foot pressure images for detection of the plantar ulcers in early-stage diabetic neuropathy

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Abstract—In this paper, studies are performed on a large number of diabetic patients belonging to different levels of plantar sensation loss, by analyzing the standing foot pressure images in the frequency domain. A new parameter, the power ratio ($PR$, the ratio of high frequency power to the total power in an image), is used to distinguish between foot pressure image patterns of diabetic neuropathic subjects (at different levels of sensation loss) and those of normal feet. The foot areas of the diabetic subjects are scanned in 10 specified areas using Semmes Weinstein's nylon monofilaments to quantify the diabetic neuropathy. A statistical study of the mean values of this parameter in different plantar areas of the feet for different levels of diabetic neuropathy indicates distinguishing trends. The result could help in the early detection of low-level sensation loss by establishing the threshold of the $PR$ in a particular area above which there could be the possibility of plantar ulcer formation. This information could be utilized by orthopedic surgeons to devise early corrective methods to protect the feet from further damage due to plantar ulcers.

Key words: Standing foot pressure image; Fourier transform; diabetic neuropathy; early detection; foot ulcer.

1. INTRODUCTION

Foot problems in patients with diabetes mellitus are a major public health concern these days. The complications of diabetes most relevant to the lower extremities are distal peripheral neuropathy and, to a lesser extent, peripheral vascular disease. The most feared lower extremity problem among patients with diabetes is amputation and the sequence of events leading to amputation is initiated by skin ulceration.

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This occurs most frequently because of a loss of sensation. While lower extremity vascular disease can be important in some patients with diabetes, most of the lower extremity problems in these patients must be viewed as being due to neuropathy. In diabetic neuropathy, all three components of the nerve are affected (sensory, motor and autonomic), although sensory symptoms are often most apparent [1].

Diabetic neuropathic ulceration commences with tissue breakdown and the formation of a cavity deep in the epithelial surface followed by subsequent ulceration of the overlying skin [2]. The mechanism starts with the formation of a plaque of unusually hard keratin, followed by tissue breakdown and formation of an ulcer with an initial small opening and a large cavity underneath. For the purpose of study, a ‘normal’ foot means one with no callosities, no physical deformity, no pain and no surgical history [3]. The peak normal standing foot pressure is of the order of 10 N/cm² [4–6]. While the ulcer risk threshold has not been completely defined, many patients ulcerate at pressures which are still ‘normal’ [1]. This fact points to the importance of loss of protective sensation (LOPS). Those of us who can feel our feet presumably alter the way we walk from time to time to prevent ulceration. This is not so in the case of diabetic neuropathic patients. Work in the literature deals with abnormal walking foot pressure distribution for diabetic neuropathic subjects as compared to normal subjects and the study was undertaken for only a few subjects [7]. Other studies [6, 8, 9] did not quantify the different levels of neuropathy while reporting the abnormal foot pressure distribution. Therefore, it becomes difficult to find early-stage neuropathy and the corresponding abnormal pressure distribution causing plantar ulcers.

Most human beings spend a large proportion of their waking hours in the standing position, yet surprisingly little information is available about the function of the foot in standing [5]. As one aspect of the function, it is useful to measure the distribution and magnitude of the pressures under the foot during standing [10]. It is also useful and easier to analyze standing foot pressure characteristics (compared to walking) of diabetic subjects at different levels of neuropathy and use to distinguish them from those of normal subjects. Because of the limitations of the earlier studies listed above, in this paper we attempt to analyze standing foot pressure images of a larger number of diabetic subjects (in 10 standard areas of the foot) at different levels of neuropathy (characterized by levels of sensation loss) and relate them to a new abnormal foot pressure distribution parameter, the power ratio ($PR$, the ratio of high frequency power to the total power in an image), so as to help in the detection of early-stage diabetic neuropathy causing plantar ulcers.

The foot areas of diabetic subjects are scanned in 10 specified areas [5, 6, 9] using Semmes Weinstein’s nylon monofilaments to determine quantitatively the degree of neuropathy. Subsequently, standing foot pressure images are obtained from the optical pedobarograph. The spatial distributions of the light intensity in the above standard areas of the foot images are subjected to fast Fourier transform (FFT) and the power distribution of the spatial frequency is obtained. The new parameter, $PR$, is evaluated in each of these areas. A statistical study is also performed to relate