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# Elevated plantar pressure in diabetic patients and its relationship with their gait features

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ABSTRACT

*Purpose:* High plantar pressure is a major risk factor for diabetic foot ulcers. The relationship between plantar pressure and foot mobility has been investigated in some studies. However, when the foot is in motion, foot mobility is only a small feature of the gait. Therefore, we investigated relationship between high plantar pressure and gait and also studied the motion of the trunk. In addition, we investigated the relationship between gait and patient characteristics to identify patients at high-risk of developing diabetic foot ulcers.

*Methods:* The relationships between elevated plantar pressure, gait features, and patient characteristics were analyzed. Plantar pressure distribution in the stance phase was divided on the four plantar segments. Elevated plantar pressure was defined as being more than the mean plus one standard deviation of the corresponding segment in non-diabetic subjects. Plantar pressure distribution was measured by an F-scan system, and gait features were measured using wireless motion sensors attached to the sacrum and feet. Patient characteristics were obtained from medical records or by interview.

*Results:* Small roll and yaw motions of the body and yaw motion of the foot during the mid-stance phase were related to the elevated plantar pressure in 57 diabetic patients. Furthermore, these gait features were related to sensory neuropathy, diabetes duration, patient weight, toe-gap force, and ankle range of motion.

*Conclusion:* Given our findings, it may be possible to prevent diabetic foot ulcers by increasing foot motion during the mid-stance phase. Passive exercise aimed at expanding ankle range of motion in patients with sensory neuropathy or long-standing diabetes may assist in achieving this.



## 1. Introduction

Diabetic foot ulcers are one of the most serious complications of diabetes and are defined as cutaneous erosions characterized by a loss of epithelium that extends into or through the dermis to deeper tissues [1]. Diabetic foot ulcers are a serious problem, with a lifetime incidence of 15%–25% in the diabetic population [2].

High plantar pressure is a major risk factor for diabetic foot ulcers [3,4]. Avoidance of high plantar pressure may aid in the prevention of foot ulcers. Increases in mean peak pressure (MPP) and pressure–time integral (PTI) in the plantar have been demonstrated as risk factors for foot ulcers [5,6]. PTI represents the amount of force or pressure that is applied during the duration of foot contact with the ground [7]. According to international consensus, foot ulcers most often develop on the big toe, metatarsal heads, medial midfoot, and center of the heel [8]. Thus, the plantar is generally divided into these four segments for analysis of plantar pressure distribution [9].

High plantar pressure is the last step in a process during which several factors contribute to the development of a diabetic foot ulcers. Two causes of high plantar pressure are foot deformity and limited range of motion (ROM) [10,11]. Custom-made footwear is often used to prevent high plantar pressure, but foot ulcers may still develop because of inadequate plantar pressure reduction [12]. Therefore, it is necessary to consider further factors that are thought to be associated with high plantar pressure. Foot ulcers

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may be caused by forces generated during gait [13]. Alterations in gait have been reported in diabetic patients [14]. However, it is not clear whether the gait features are related to high plantar pressure. Different plantar segments dominate during each phase of the gait cycle. Plantar pressure is related to the stance phase, during which the limb is in contact with the ground. In general, the heel segment determines plantar pressure in the heel-strike phase, whereas midfoot and forefoot segments determine plantar pressure in the mid-stance phase. The toes determine plantar pressure in the push-off phase. Although gait features and plantar pressure have been simultaneously measured in few studies, these studies had not been investigated these relationship [15,16]. These relationship has been only partially investigated. Compared with non-diabetic subjects, patients with diabetic neuropathy have shown reduced active ankle ROM and dynamic ankle flexion in the heel-strike phase and reduced amplitude of ROM (flexion–extension). High MPP and PTI are common in the forefoot segment during the push-off phase in diabetic patients, indicating overload in the high-risk segment of the plantar [17]. Research has shown a negative correlation between the sagittal motion of the first metatarsal and forefoot and frontal motion of the calcaneus to PTI in diabetic patients [18]. In clinical settings, use of only segmental foot mobility is limited. We hypothesized that it will be more effective that the body motion and foot motion intervention are combined. Therefore, in this study, motions of body as well as foot mobility were used to assess gait. Further, the relationship between the gait features and plantar pressure was investigated.

In diabetic patients, changes in gait features are related to characteristics such as neuropathy and diabetes itself. For example, a significantly different walking motion has been observed between diabetic patients with neuropathy and diabetic patients without neuropathy [19]. Another study demonstrated that some gait features are significantly altered before clinical detection of neuropathy [20]. In addition, because of the resultant glycation of collagen-rich tissues, such as tendons, ligaments, and skin, diabetic patients often have limited joint mobility [21]. Limited ankle joint mobility is common in diabetic patients, with or without neuropathy, thus suggesting that other mechanisms, besides neuropathy, may contribute to changes in foot and ankle biomechanics [22]. Reduced protein synthesis causes decreased muscle strength, which is in turn related to the severity of diabetes [23]. Clarification of the relationships between high plantar pressure, gait features, and patient characteristics is required for the effective prevention of high plantar pressure and to allow patient's conscious change in the gait features or patient characteristics.

High plantar pressure has been given a number of different definitions in the literature. Some studies have identified cut-off values for the accurate prediction of the risk of diabetic foot ulcers in diabetic patients with increased plantar pressure [24,25]. However, no cut-off values have been distinguished for each individual segment of the plantar, despite differences in these segments being demonstrated in a previous study [26]. Thus, plantar pressure in diabetic patients must be compared with that of non-diabetic subjects to distinguish what constitutes elevated plantar pressure and to investigate whether it is different for plantar segments.

Therefore, the purpose of this study was (1) to reveal what gait features are related to the elevated segment and its plantar pressure, (2) to clarify characteristics that may be related to changes in the gait features and the elevated plantar pressure in diabetic patients.

## 2. Methods

### *2.1. Subjects and setting*

This cross-sectional observational study was conducted at the Diabetic Foot Outpatient Clinic at the University of Tokyo Hospital, from April 2012 to October 2012. All diabetic patients who visited this outpatient clinic during this period were recruited. Non-diabetic subjects of matched age and sex were volunteers selected by the snowball sampling method. Subjects who could not walk unaided, those with a current diabetic foot ulcers, those with a history of lower extremity orthopedic problems, those who could not provide consent for participation, and those who had difficulty wearing the measurement footwear (foot length >26.5 cm) were excluded from the study. The study protocol was approved by the Ethical Committee of the Graduate School of Medicine, the University of Tokyo (#3694).

### *2.2. Measurement system*

Plantar pressure distribution and gait features were measured simultaneously [Fig. 1 (A)]. We synchronized measurements by beginning at the moment when plantar pressure appeared and measured the impact waveform of each heel-contact after the measurement. Plantar pressure was measured by an F-scan (NITTA CORPORATION, Osaka, Japan) inserted into the footwear. Gait was

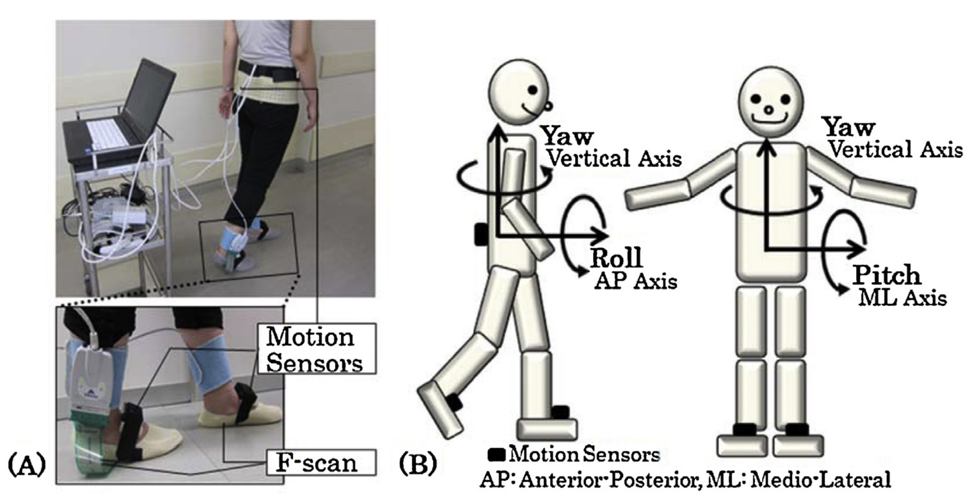


**Fig. 1.** (A) Measurement system (B) Three-dimensional axes.