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Effect of heel height on in-shoe localized triaxial stresses

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ABSTRACT

Abnormal and excessive plantar pressure and shear are potential risk factors for high-heeled related foot problems, such as forefoot pain, hallux valgus deformity and calluses. Plantar shear stresses could be of particular importance with an inclined supporting surface of high-heeled shoe. This study aimed to investigate the contact pressures and shear stresses simultaneously between plantar foot and high-heeled shoe over five major weightbearing regions: hallux, heel, first, second and fourth metatarsal heads, using in-shoe triaxial force transducers. During both standing and walking, peak pressure and shear stress shifted from the lateral to the medial forefoot as the heel height increased from 30 to 70 mm. Heel height elevation had a greater influence on peak shear than peak pressure. The increase in peak shear was up to 119% during walking, which was about five times that of peak pressure. With increasing heel height, peak posterolateral shear over the hallux at midstance increased, whereas peak pressure at push-off decreased. The increased posterolateral shear could be a contributing factor to hallux deformity. It was found that there were differences in the location and time of occurrence between in-shoe peak pressure and peak shear. In addition, there were significant differences in time of occurrence for the double-peak loading pattern between the resultant horizontal ground reaction force peaks and in-shoe localized peak shears. The abnormal and drastic increase of in-shoe shear stresses might be a critical risk factor for shoe-related foot disorders. In-shoe triaxial stresses should therefore be considered to help in designing proper footwear.

1. Introduction

The increasing popularity of high-heeled shoes can be attributed to modern fashion, job requirement and common belief in enhancing esthetic appeal. Wearing high-heeled shoes would change body alignment and muscle activities, redistribute the plantar pressure and ground reaction forces (GRFs), thus inducing clinical problems of lower extremity (de Lateur et al., 1991; Esenyel et al., 2003; Gefen et al., 2002; Hong et al., 2005; Linder and Saltzman, 1998). Forefoot pain, hallux valgus and calluses are among the common foot problems encountered by long-term wearers (Al-Abdulwahab and Al-Dosry, 2000; Dawson et al., 2002; Dunn et al., 2004; Kernozek et al., 2003; Menz and Morris, 2005), which are thought to be associated with excessive plantar mechanical stresses, including pressure and shear, whose distributions are influenced by shoe construction and its materials.

Heel height elevation is correlated with the prevalence of hallux valgus (Dawson et al., 2002; Menz and Morris, 2005). Hallux valgus deformity was thought to be caused by a disturbed flexor halluics longus balance at the first metatarsophalageal joint (Glasoe et al., 2010; Snijder et al., 1986). High-heeled shoes change the foot alignment and redistribute the plantar stresses, which might lead to an imbalance of muscle moment especially when external stresses force the hallux to abduct and thus triggering hallux deformity.

In high-heeled shoes, shear stress might be of particular importance with an inclined supporting surface, which would increase the risk of soft tissue problems. Excessive shear forces result in the thickening of the stratum corneum, leading to hyperkeratosis (MacKenzie, 1974). Shear stress together with pressure could occlude the blood circulation (Bennet et al., 1979; Dinsdale, 1974; Zhang and Roberts, 1993), which would reduce tissue tolerance or repair capability and make foot vulnerable to damages. Plantar pressure alone is not sufficient in predicting foot disorders related to the plantar tissue (Lavery et al., 2003; Veves et al., 1992). Combined effects of pressure and shear stresses should be considered, including magnitudes, directions and spatiotemporal properties.

Although the resultant applications of pressure and shear on the skin surface has been suggested as critical variables for skin contact mechanics (Zhang and Roberts, 1993; Zhang et al., 1994), there have been limited reports on in-shoe triaxial stresses measurement due to lack of the proper instrument. Some

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