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Low stiffness floors can attenuate fall-related femoral impact forces by up to 50% without substantially impairing balance in older women

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ABSTRACT

Low stiffness floors such as carpet appear to decrease hip fracture risk by providing a modest degree of force attenuation during falls without impairing balance. It is unknown whether other compliant floors can more effectively reduce impact loads without coincident increases in fall risk.

We used a hip impact simulator to assess femoral neck force for four energy-absorbing floors (SmartCell, SofTile, Firm Foam, Soft Foam) compared to a rigid floor. We also assessed the influence of these floors on balance/mobility in 15 elderly women.

We observed differences in the mean attenuation in peak femoral neck force provided by the SmartCell (24.5%), SofTile (47.2%), Firm Foam (76.6%), and Soft Foam (52.4%) floors. As impact velocity increased from 2 to 4 m/s, force attenuation increased for SmartCell (from 17.3% to 33.7%) and SofTile (from 44.9% to 51.2%), but decreased for the Firm Foam (from 87.0% to 64.5%) and Soft Foam (from 66.1% to 37.9%) conditions. Regarding balance, there were no significant differences between the rigid, SmartCell, and SofTile floors in proportion of successful trials, Get Up and Go time, balance confidence or utility ratings. SofTile, Firm Foam, and Soft Foam caused significant increases (when compared to the rigid floor) in postural sway in the anterior-posterior and medial-lateral directions during standing. However, SmartCell increased sway only in the anterior-posterior direction.

This study demonstrates that two commercially available compliant floors can attenuate femoral impact force by up to 50% while having only limited influence on balance in older women, and supports development of clinical trials to test their effectiveness in high-risk settings.

1. Introduction

Hip fractures are a major health problem for the elderly, with approximately 23,000 annual cases in Canada and associated treatment costs of about $1 billion (Papadimitropoulos et al., 1997). Over 25% of hip fracture patients will die within one year after the fracture, and over 50% will suffer a major decline in mobility and functional independence (Norton et al., 2000; Wolinsky et al., 1997). Over 90% of hip fractures are caused by falls (Grisso et al., 1991), underlying the need for fracture prevention programs to focus on reducing the frequency and severity of falls, in addition to enhancing bone strength.

Hip fractures often occur in environments where there is a high density of frail elderly, such as residential care facilities, hospitals, and senior centres. A promising strategy for reducing fracture incidence in these settings is to decrease the stiffness of the ground surface, and the subsequent force applied to the proximal femur in the event of a fall (Casalena et al., 1998a). Indeed, epidemiological evidence indicates that falling onto padded carpet, grass, or loose dirt reduces hip fracture risk when compared to falling on concrete or linoleum (Healey, 1994; Nevitt and Cummings, 1993; Simpson et al., 2004). Furthermore, laboratory studies show that, when compared to falling on a rigid surface, a 4.5 cm thick layer of foam rubber reduces the peak force to the hip by 15% (Laing et al., 2006; Sran and Robinovitch, 2008) and the peak pressure over the greater trochanter by 76% (Laing and Robinovitch, 2008a). While even softer floors should provide greater attenuation in fall impact force, excessive reduction in floor stiffness may impair mobility and balance and lead to increased risk for falls. This may occur via several mechanisms, including decreases in the quality of information from ankle proprioceptors and pressure receptors on the plantar foot surface (Betker et al., 2005; Lord and Menz, 2000; Ring et al.,

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1989), a reduction in toe clearance during walking, an increase in energy expenditure during walking (Redfern et al., 1997), and a decrease in the total effective stiffness of the ankles.

Accordingly, a crucial question is the following: how soft can floors be designed (and what corresponding level of force attenuation can be achieved during a fall), before they create an unacceptable impairment in balance and mobility, and increased risk for falls? No study to date has addressed this issue. As a first step towards answering this question, our objectives in the current study were: (a) to measure the force attenuation provided by a range of commercially available low stiffness floors during simulated sideways falls on the hip, and (b) to determine whether these floors influence balance and mobility in healthy elderly women.

2. Methods

2.1. Floor conditions

We investigated five flooring types selected to provide a wide range of floor stiffness conditions (Fig. 1A). The ‘rigid’ control floor was a 2 mm thick layer of slip-resistant dense natural rubber intended for use in commercial and institutional settings (Noraplan Classic, Nora Systems Inc., Lawrence, MA, USA). SmartCell (SATech, Chehalis, WA, USA) is a synthetic rubber (density = 1120 kg/m^3) floor system comprising a continuous surface layer overlying an array of cylindrical rubber columns 14 mm in diameter, and spaced at 19 mm intervals (Fig. 1B). The version we tested had a height of 2.5 cm. The SofTile floor (SofSurfaces, Petrolia, ON, Canada) consists of square tiles of synthetic rubber typically used as playground surfaces. Each 60 cm × 60 cm × 10 cm tile comprises a continuous top surface overlying compliant rubber columns 5 cm in diameter spaced at 7 cm intervals, and interfaces with adjacent sections via interlocking flanges (Fig. 1B). Two additional conditions were comprised of open cell polyurethane foams from gymnasium crash mats. The Firm Foam condition was 11 cm thick with a density of 32 kg/m^3, while the Soft Foam was 10 cm thick with a density of 22.2 kg/m^3 (The Foam Shop, Vancouver, Canada). The Indentation Load–Deflection (ILD) test is a standard measure of foam firmness in which samples (100 mm thick by 500 mm by 500 mm) are statically loaded with a flat circular indenter (10.1 cm radius) (Mills, 2007). The *ILD25* value is the load associated with a sample strain of 25%, and was 400 N for the Firm Foam and 195 N for the Soft Foam (as reported by the manufacturer).

We measured the force–deflection properties of each floor through indentation tests with a servohydraulic testing system

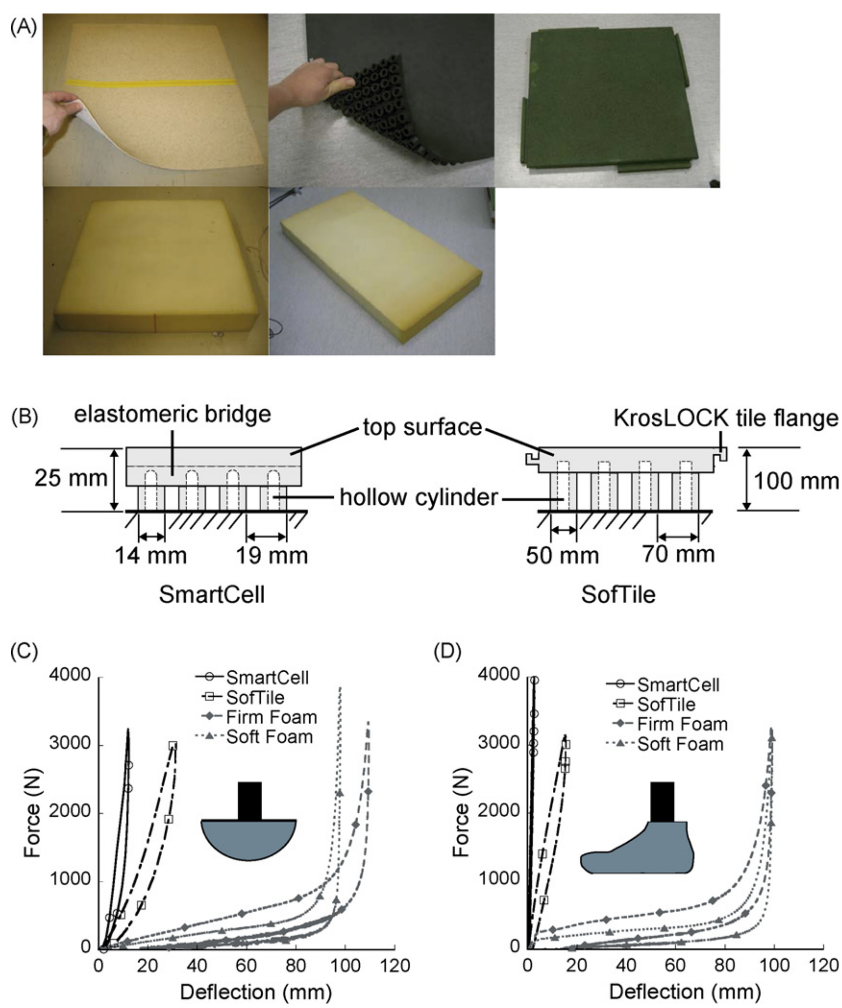

Fig. 1. Details of the floors tested. (A) Pictures (clockwise from top left): Rigid, SmartCell, SofTile, Firm Foam, Soft Foam. (B) Cross-sectional schematics of SmartCell and SofTile floors. SmartCell comprises synthetic rubber in a continuous surface layer overlying an array of cylindrical rubber columns 14 mm in diameter, and spaced at 19 mm intervals – the version we tested had a height of 25 mm. SofTile is constructed with a continuous rubber top surface overlying compliant rubber columns 5 cm in diameter, spaced at 7 cm intervals, and 10 cm in height. The Firm Foam and Soft Foam conditions (not shown) comprised open cell polyurethane. The Firm Foam had a height of 11 cm and a density of 32 kg/m^3; the Soft Foam had a height of 10 cm and a density of 22.2 kg/m^3. (C) Force–deflection properties using a hip-shaped indenter. (D) Force–deflection properties using a foot-shaped indenter.