Compliant flooring for fracture prevention in high-risk environments: effects on fall severity, mobility, and balance

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Introduction

- Hip fractures often occur in environments with a high density of frail older adults (LTC facilities, hospitals, senior centres).

- Fracture incidence in these settings might be reduced by decreasing the stiffness of the ground surface, and the force applied to the bone during impact.

- Falls on concrete or linoleum create greater risk for fracture than falls on padded carpet, grass, or loose dirt (Healey, 1994; Nevitt and Cummings, 1993; Simpson et al., 2004).
• previous studies report that peak force during a fall on the hip is reduced 7% by wooden floors, 15% by carpets, 24% for carpets with foam padding, and 15% by a dual-stiffness floor (Gardner et al., 1998; Maki and Fernie, 1990; Simpson et al., 2004; Casalena et al., 1998);

• while softer floors should provide greater force attenuation, excessive reduction in floor stiffness may impair mobility and balance, and increase risk for falls (e.g., by affecting postural sway, toe clearance during gait, energy expenditure during ADL’s)
Impact force reduction (%) vs. Floor stiffness (kN/m)

attainable force reduction

Mobility and balance vs. Floor stiffness (kN/m)

acceptable level of impairment

CEMFIA Residential Care Summit: "Fall & Injury Prevention Research to Action"  Nov 5, 2009
General research question:
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?

Study objectives:
(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 older women.
Methods: Floor conditions

- Rigid: Noraplan Classic rubber flooring (2 mm thick)
- Smartcell anti-fatigue mat (25 mm thick)
- SofTile playground tile (100 mm thick)
- “Firm Foam” and “Soft Foam” (100 mm thick) open cell polyurethane
- Surface area: 60 cm x 60 cm
Methods: Force attenuation tests
SFU Hip Impact Simulator

- matches surface geometry and soft tissue stiffness of of older women (Laing et al., 2008)
- matches effective mass and stiffness of body during impact to the hip (Robinovitch et al., 1997)
- Each sample tested at impact velocities of 2, 3, and 4 m/s
- Repeated measures ANOVA on the effect of floor condition and impact velocity on percent reduction in peak force applied to the femoral neck, relative to stiff floor condition
Methods: Balance tests with older women

- 15 women ranging in age from 65 - 90 yrs (mean = 75, SD = 8)

- Tests:
  - Get Up and Go
  - sway during quiet stance
  - balance recovery following floor translation
  - balance confidence, utility ratings

- Repeated measures ANOVA to determine the effect of floor type on outcomes from each test
Results: Force attenuation tests

- Floor type significantly influenced force attenuation (p < 0.001):
  - 25% (SD=8) for SmartCell;
  - 47% (SD=4) for SofTile;
  - 77% (SD=11) for Firm Foam
  - 52% (SD=14) for Soft Foam
- Significant interaction between impact velocity and floor type (p<0.001)
Results: Balance tests with older women

<table>
<thead>
<tr>
<th></th>
<th>Rigid</th>
<th>SmartCell</th>
<th>SoftTile</th>
<th>Firm Foam</th>
<th>Soft Foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>$GUG_{time} (s)$</td>
<td>11.7 (1.9)</td>
<td>11.4 (1.9)</td>
<td>12.0 (2.4)</td>
<td>14.0 (3.2)$^b$</td>
<td>14.0 (3.1)$^b$</td>
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<tr>
<td>success$^c$</td>
<td>BFT 0.79 (0.36)</td>
<td>0.85 (0.32)</td>
<td>0.79 (0.33)</td>
<td>0.45 (0.42)$^b$</td>
<td>0.67 (0.38)</td>
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<tr>
<td></td>
<td>RGUG 0.65 (0.4)</td>
<td>0.53 (0.36)</td>
<td>0.52 (0.38)</td>
<td>0.27 (0.34)$^b$</td>
<td>0.25 (0.27)$^b$</td>
</tr>
<tr>
<td>$RMS_{ap} (mm)$</td>
<td>EO 3.3 (0.9)</td>
<td>4.2 (1.3)$^b$</td>
<td>4.5 (0.9)$^b$</td>
<td>7.0 (1.2)$^b$</td>
<td>5.0 (1.3)$^b$</td>
</tr>
<tr>
<td></td>
<td>FC 3.7 (1.2)</td>
<td>4.2 (1.3)</td>
<td>5.4 (1.7)$^b$</td>
<td>11.4 (3.8)$^b$</td>
<td>6.5 (1.8)$^b$</td>
</tr>
<tr>
<td>$RMS_{ml} (mm)$</td>
<td>EO 1.2 (0.3)</td>
<td>1.5 (0.6)</td>
<td>1.7 (0.6)$^b$</td>
<td>5.8 (2.4)$^b$</td>
<td>2.5 (1.1)$^b$</td>
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<td></td>
<td>EC 1.4 (0.5)</td>
<td>1.5 (0.5)</td>
<td>2.2 (1.1)$^b$</td>
<td>9.2 (4.8)$^b$</td>
<td>3.0 (1.7)$^b$</td>
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<tr>
<td>$vel_{ap} (mm/s)$</td>
<td>EO 8.0 (2.4)</td>
<td>9.1 (3.2)$^b$</td>
<td>9.3 (2.3)$^b$</td>
<td>20.3 (6.5)$^b$</td>
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<td></td>
<td>EC 11.5 (3.6)</td>
<td>12.1 (4.0)</td>
<td>15.1 (5.9)$^b$</td>
<td>40.3 (18.8)$^b$</td>
<td>21.1 (6.6)$^b$</td>
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<td>$vel_{ml} (mm/s)$</td>
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<td>3.9 (1.1)</td>
<td>4.4 (1.1)$^b$</td>
<td>11.0 (4.5)$^b$</td>
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<td></td>
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<td>4.7 (1.3)</td>
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<td>5.5 (3.1)$^b$</td>
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<td>utility</td>
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<td>8.5 (1.8)</td>
<td>8.2 (2.4)</td>
<td>2.6 (2.6)$^b$</td>
<td>1.9 (2.4)$^b$</td>
</tr>
</tbody>
</table>

$^b$ Significantly different from the rigid floor ($p < 0.001$)
Discussion

• Currently available flooring systems (e.g. SmartCell and SofTile floors) can attenuate femoral neck impact force by up to 47%, while causing minimal effects on postural stability in older women.

• Further reductions in floor stiffness, while leading to greater force attenuation, caused substantial negative effects on postural sway, balance recovery ability, and balance confidence, and were rated as impractical by the study participants.
• SmartCell deflected less than 1 mm (and SofTile deflected 4 mm) under a 1000 N footfall

• SmartCell and SofTile did not “bottom out” under our test conditions - force attenuation increased with increasing impact velocity

• Firm Foam and Soft Foam floors bottomed out under the 2 m/s impacts, and provided less protection for higher energy impacts
• Hip protectors reduce peak impact force by 21% on average (Laing et al., 2008) – 16% less than SmartCell and 55% less than SofTile

• Unlike hip protectors, compliant flooring is a passive intervention, not dependent on user compliance

• Assuming a reduction in fracture incidence of 50%, and a 6-fold higher installation cost than standard flooring, the pay-off period for compliant flooring would be ~1.5 years

• These results support the need for clinical trials to assess efficacy in reducing injuries, and biomechanical testing standards to guide market approval of this technology
Acknowledgements

IPML Trainees (current and past):
Andrew Laing, PhD
Fabio Feldman, PhD
Joseph Choi, PT, MSc
Jimmy Tsai, MSc
Kim Cheema, BSc

Funding:
NSERC, MSFHR, CFI, Tytex A/S