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Development of a stick-on hip protector: A multiple methods study to improve hip protector design for older adults in the acute care environment

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Abstract

Introduction: Over 90% of hip fractures in older adults result from falls, and hospital patients are at especially high risk. Specific types of wearable hip protectors have been shown to reduce hip fracture risk during a fall by up to 80%, but user compliance has averaged less than 50%. We describe the development and evaluation of a "stick-on" hip protector (secured over the hip with a skin-friendly adhesive) for older patients in acute care.

Methods: An initial version of the product was evaluated with six female patients (aged 76–91) in a hospital ward, who were asked to wear it for one week. We subsequently refined the product through biomechanical testing and solicited feedback from 43 health professionals on a second prototype.

Results: The first prototype was worn by five of six patients for the full week or duration of their hospital stay. The second prototype (20 mm thick, surface area 19×15.5 cm) provided 36% force attenuation, more than common garment-based models (20–21%). Feedback from patients and health professionals highlighted usability, comfort, cost, and appearance.

Conclusions: Our results from biomechanical and user testing support the need for further work to determine the value of stick-on hip protectors in acute care.

Keywords

Acute care, hospital, aging, falls, hip fracture, hip protector, hip pad, injury prevention, protective gear

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Introduction

Falls are the cause of at least 90% of hip fractures in older adults.[1,2] Hip protectors are wearable devices that are intended to reduce the force applied to the proximal femur and the related risk for hip fracture during a fall.[3] Specific types of hip protectors have been shown in clinical trials to reduce the risk for hip fracture by up to 80% when worn. However, user compliance with conventional garment-based hip protectors averages less than 50%[4–6] and has been reported to be under 25% in acute care settings.[7] Barriers to user compliance with hip protectors include comfort, cost, and challenges with laundering, donning, and doffing.[8–14]

To address these barriers to compliance, we developed a novel "stick-on" hip protector, which adheres directly to the person's skin. Stick-on hip protectors may improve comfort, by precluding the need for additional undergarments to mount the protector, which have been reported as "too hot" or "too tight."[9,10,14] Furthermore, stick-on protectors may improve the real and perceived efficacy for hip fracture prevention by preventing shifting of the pad relative to the skin surface[15–17] and by providing continuous protection. Stick-on hip protectors may also facilitate ease of use for wearers and care staff by eliminating the challenges

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of donning and doffing garment-mounted protectors when toileting[9,12] and laundering.[13,18] However, for a stick-on hip protector to serve as an acceptable alternative to existing garment-based models, it must provide at least as much protection in the event of a fall, and not be so bulky that potential users deem it unacceptable to wear.[4,8,19]

In this study, we examined the experiences of hospital patients in wearing a first prototype of a stick-on hip protector, having a geometry that was modeled on an existing soft-shell hip protector. We then conducted biomechanical tests to refine the hip protector geometry. Finally, we sought feedback from healthcare professionals on a second prototype.

Materials and methods

Our development process for the stick-on hip protector is summarized in Figure 1. To establish proof-of-concept, we started by conducting initial user testing that explored the willingness of hospital patients to wear an early version of the stick-on hip protector (described in the "Initial user testing of a stick-on hip protector with hospital patients" section). We then conducted biomechanical testing to improve the design of the stick-on hip protector in terms of surface geometry and thickness, while maintaining the same adhesive (described in the "Biomechanical effectiveness and influence of pad geometry and thickness" section). Finally, we obtained feedback from health professionals on the second iteration of the stick-on hip protector (described in the "Feedback fair with healthcare professionals, for an improved ("large donut hole") hip protector model" section). All stick-on hip protector pads were made with a polymeric foam stock with a hardness of approximately 60 durometer, which has been reported to provide higher force attenuation during simulated sideways falls on the hip than softer or harder foams.[20] Both the pilot hospital testing and feedback collection from health professionals involved human participants, all of whom provided written informed consent. Participants were not offered compensation for this study. Both the Office of Research Ethics at Simon Fraser University and the Fraser Health Research Ethics Board approved this study.

Initial user testing of a stick-on hip protector with hospital patients

Participants. We performed user testing of a stick-on hip protector in a Medicine unit at Burnaby Hospital (Burnaby, Canada). Six female patients (76–91 years) were offered the opportunity to wear a preliminary pad prototype (Figure 2(c)) for seven consecutive days during their hospital stay. While the seven-day duration

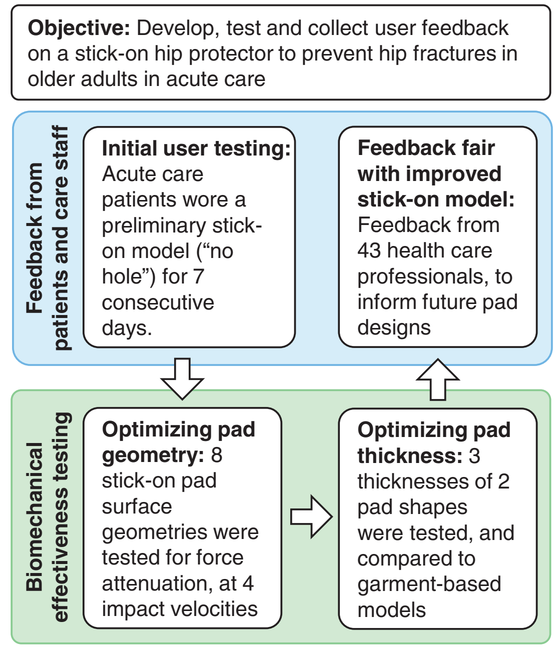

Figure 1. Summary of protocol.

is lower than the average length of stay in hospital for individuals aged 70–90+ in British Columbia (8.9–13.6 days[21]), it allowed us to collect early stage evidence on the practical potential of the concept, and feedback to inform improvements to the hip protector design. All data were collected over a two-week period. The product provided to patients was 16 mm thick and had a surface area of 19×15.5 cm (Version 1 in Figure 2(c)). The pad was designed with a geometry similar to the "HipSaver" garment-based pad, which is a "standard of care" model for Burnaby Hospital patients. The pad was attached to the skin using hypo-allergenic, skin-friendly tape. The tape was selected for its strong adhesion over a long period (21 days even after removal and re-application, according to manufacturer specifications).

Protocol. Consenting patients were asked to wear a prototype pad for seven consecutive days. Nursing staff were asked to remove the pads daily to inspect the skin for side effects and to monitor the quality of adhesion. Nurses also provided daily reports on issues related to use, based on direct observation and feedback from patients and caregivers. Nurses recorded data in Medical Administration Record binders during morning, evening, and night shifts.

Biomechanical effectiveness and influence of pad geometry and thickness

Instrumentation and protocol. Impact testing was conducted with a hip impact simulator (Figure 2(b)),

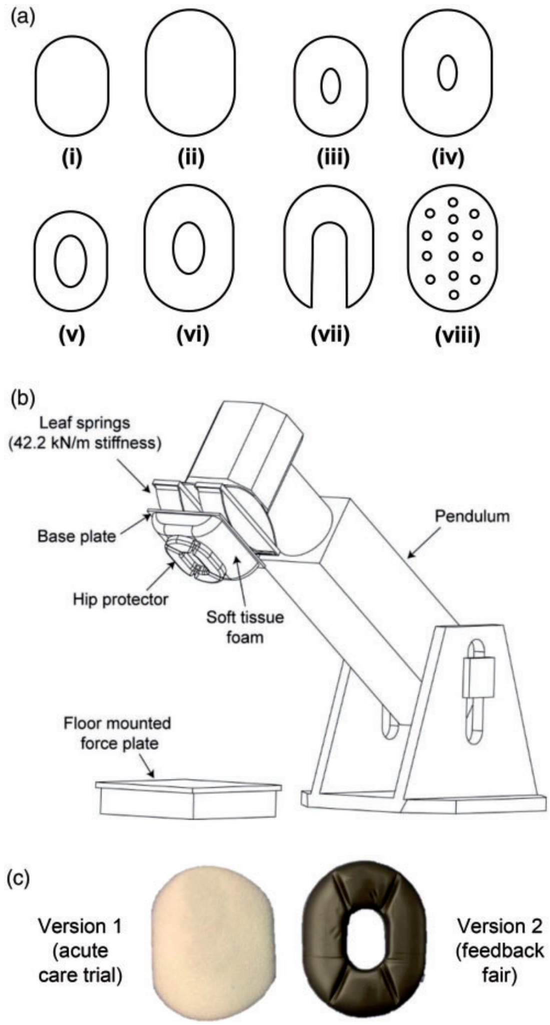

Figure 2. (a) Variations in pad surface geometry: (i) 17 × 13.5 cm and (ii) 19 × 15.5 cm "no hole" pads (having a continuous surface); (iii) 17 × 13.5 cm and (iv) 19 × 15.5 cm "small donut hole" pads (donut-shaped with an inner hole of 4 cm width); (v) 17 × 13.5 cm and (vi) 19 × 15.5 cm "large donut hole" pads (donut-shaped with an inner hole of 6 cm width); (vii) 19 × 15.5 cm "horseshoe" pad (shaped like a horseshoe, with the top portion of the pad resting above the greater trochanter); and (viii) 19 × 15.5 cm vented holes pad. Image is not to scale. (b) Schematic diagram of the impact pendulum used in biomechanical testing. A hip protector is mounted to the base plate on the pendulum, which drops on to a force plate. A load cell measures impact forces to the simulated femoral neck. (c) Pad transformation from the preliminary Version 1 (used in the acute care trial) to the Version 2 pad (used in the Feedback Fair). The changes to pad geometry between Version 1 and Version 2 were informed by biomechanical testing and user feedback from acute care.

which simulates the dynamics of a fall from standing height onto the hip and provides measures of the peak force applied to the proximal femur during impact.[22] The system is compatible with international consensus statements[23] and existing guidelines[24] for biomechanical testing of hip protectors. The outcome measure of performance for a given hip protector was "force attenuation," defined as the percent decrease in peak force, when compared to the baseline unpadded condition. During testing, each hip protector prototype was centered over the greater trochanter and secured to the pelvis with double-sided adhesive tape. Impact forces at the femoral neck were collected with a load cell (Model 9712B5000, Kistler, Amherst, NY).

During the testing sessions, we first examined the effect of surface geometry and impact velocity on force attenuation, and then examined the effect of pad thickness on force attenuation for the top-performing surface geometry. Each prototype was tested in three repeated trials at a given impact velocity. We also conducted three "unpadded" trials at the beginning and end of each test session. In all trials, force data were sampled for 2 s at 1000 Hz, and filtered with a low-pass, fourth-order recursive Butterworth filter with a cut-off frequency of 35 Hz (LabVIEW v. 6.1, National Instruments, Austin, TX).

Surface geometry optimization. To characterize the influence of surface geometry on force attenuation, we tested eight pads (Figure 2(a)) having the following surface areas and geometries: (i) 17 × 13.5 cm and (ii) 19 × 15.5 cm "no hole" pads (having a continuous surface); (iii) 17 × 13.5 cm and (iv) 19 × 15.5 cm "small donut hole" pads (donut-shaped with an inner hole of 4 cm width); (v) 17 × 13.5 cm and (vi) 19 × 15.5 cm "large donut hole" pads (donut-shaped with an inner hole of 6 cm width); (vii) 19 × 15.5 cm "horseshoe" pad (shaped like a horseshoe, with the top portion of the pad resting above the greater trochanter); and (viii) 19 × 15.5 cm vented holes pad. All pads were 16 mm thick.

We tested all eight stick-on pad geometries at impact velocities of 2.0, 3.0, 3.4, and 4.0 m/s. The lowest impact velocity (2.0 m/s) matches the mean value of the vertical velocity of the hip during standing-height falls in older adults of 2.0 (SD = 1.0) m/s.[25] While these measures were based on analysis of videos of falls by older adults in long-term care, there is little reason for believing that the impact velocity of the pelvis during falls in the hospital setting would be different than in falls observed in long-term care. An impact velocity of 3.4 m/s is recommended in international guidelines on biomechanical testing of hip protectors[23] and represents a severe fall. We also included velocities of 3.0 and 4.0 m/s, since a previous study reported force attenuations provided by 26 different garment-mounted hip protectors at impact velocities of 2.0, 3.0, and 4.0 m/s.[26]

Pad thickness optimization. To characterize the effect of pad thickness on force attenuation, we tested three thicknesses (16, 20, and 24 mm) of the 17 × 13.5 cm and

19 × 15.5 cm "large donut hole" pads. We also tested two commercially available, garment-based hip protectors that were commonly used in hospitals within the Fraser Health Authority: (1) HipSaver® (HipSaver Canada, Exeter, ON, Canada) and (2) SAFEHIP® Soft AirX™ (Tytex A/S; Ikast, Denmark). HipSaver® and SAFEHIP® Soft AirX™ had thicknesses of 18 and 16 mm, respectively. These tests were conducted using an impact velocity of 3.4 m/s, for consistency with international guidelines.[23]

Biomechanical data analysis. For each hip protector, force attenuation at a given impact velocity was calculated as the percent decrease in peak femoral neck force compared to the peak femoral force in the unpadded condition (mean of the first three and last three unpadded trials). The difference in unpadded force averaged over the first and last three unpadded trials was always less than 2% of the mean value.

We used two-way analysis of variance to quantify the effect on force attenuation of (a) impact velocity and pad surface geometry (with eight shapes), and (b) pad thickness and surface area (for large donut hole protectors). In these analyses, each trial was treated as an independent event.[15] Where significant main effects were observed, we examined paired differences using Tukey's HSD post-hoc comparisons. All analyses were conducted with JMP (Version 13.0.0) statistical analysis software. A significance level of alpha = 0.05 was used for all comparisons.

Feedback fair with healthcare professionals, for an improved ("large donut hole") hip protector model

Participants. We solicited feedback on a second prototype (Version 2) stick-on hip protector through a one-day "Feedback Fair" with care staff from two units at Surrey Memorial Hospital: Medicine and Acute Care for Elders (ACE). These units were selected for their expertise: both units used garment-based hip protectors with their patients daily.

Feedback fair design. Feedback fairs are intended to provoke conversations and encourage knowledge exchange between participants as they travel through "stations," without requiring a substantial time commitment from participants, whose schedules may not be feasible to coordinate.[27] This method of qualitative engagement allowed us to involve a large number of health professionals while minimizing disruption to their work in a busy hospital environment.[27] For this fair, the stations included:

(1) Introduction to the fair: A researcher explained the study and provided background information on garment-based hip protectors, including their role in preventing hip fractures. Participants were also made aware of the goals of the fair: to gather clinical perspectives on hip protectors, and feedback on the stick-on model, which the research team could use to improve the protector's design.
(2) Feedback on garment-mounted protectors: Participants shared their opinions (via sticky notes) on barriers to compliance with garment-based protectors and strategies for overcoming these barriers.
(3) Introduction to stick-on protectors: A researcher introduced the "large donut hole" stick-on hip protector prototype (Figure 2(c); Version 2) and explained findings from biomechanical effectiveness and pilot hospital testing.
(4) Interactive poster on stick-on protectors: Participants were given sticky notes and were invited to share their initial "likes" and "dislikes" of the stick-on hip protector prototypes. The sticky notes were mounted to a poster. Two stick-on prototypes (Figure 2(c); Version 2) were available for participants to manipulate and inspect.
(5) Questionnaire: Participants were given a questionnaire that probed their opinions on design features of the stick-on hip protector prototypes (including color, shape, size, thickness, and stiffness) and an evaluation of the Feedback Fair experience. Sample questions included: (1) Do you like the surface area of the stick-on hip protector prototype? Yes/No. If "no," how would you change it?; and (2) Do you like the color of the stick-on hip protector prototype? Yes/No. If "no," what color would you prefer?. Participants filled out the questionnaire anonymously, though denoted their job title and expertise on the form.

Data collection and analysis. Three researchers attended the Feedback Fair to collect data, converse with participants, answer questions related to the stick-on protectors, and commence preliminary analysis. These researchers were a Masters-level qualitative health researcher (EP) and two research assistants. Data were collected in three formats: field notes from conversations between researchers and participants, sticky notes from the interactive poster at Station 4 (on stick-on protectors), and the questionnaire from Station 5. To confirm that the field notes appropriately and accurately represented the views of participating health professionals, researchers performed a form of "member checking" by summarizing or re-stating major points to participants during conversation. Data from the field notes, questionnaires, and sticky notes were entered by EP into Word documents, in structural coding charts.[28] Structural coding is the preliminary phase of coding in which segments of text are assigned initial content-based descriptive codes.[28] In this study, the initial codes included patient comfort, sizing and fit, education, laundering, compliance, availability, issues related to dementia, issues related to incontinence, waste, and nodes for "likes" and "dislikes." Initial codes were reviewed by the data collection team and AMBK; EP then continued with thematic coding, in which the codes label the "bigger picture" ideas identified in the data.[28] This level of thematic analysis is reflected in the results below. Strategies for rigor included in situ conversations with participants, to ensure that our team's interpretation of their feedback resonated with them;[29] peer debriefing after the Feedback Fair to review field notes and preliminary themes;[30] team-based data analysis[30] led by EP; and reflective memoing throughout the analysis process.[31]

Results

User testing with hospital patients

Four of the six patients approached for participation wore the Version 1 stick-on protector for the seven-day period, while one patient wore the stick-on hip protector for five days before being discharged early from the hospital (Table 1). Of the five patients who participated, three had no complaints about discomfort, one complained about discomfort at night only (and thus only wore them during the day), and one found them uncomfortable but wore them anyway. The patient who refused to participate had previously refused to wear garment-based hip protectors.

No side effects were reported related to the adhesive tape and there were no complaints of pain when removing the pads. Only one patient had problems with loss of adhesive stickiness after bathing. Cleaning and fully drying the skin before reapplying the pad solved this problem.

There were some comments on underwear and incontinence products "catching" on the edges of the pad when pulling them down. Adhesion while sleeping was also a challenge: pads sometimes fell off patients if they turned or moved in the bed.

We incorporated findings from the Version 1 feedback collection into the Version 2 prototype (for use in the Feedback Fair) in two major ways. First, we selected pad geometry that would limit the potential for catching on undergarments, and tapered the edges of the pad. Second, we added grooves to the top of the protector, to improve its ability to bend with the person and remain adhered to the skin.

Biomechanical effectiveness testing

Influence of impact velocity and surface geometry (full set of protectors). Impact velocity significantly affected force attenuation ($F(3,64) = 2349.46$; $p < .0001$; Figure 3), which generally decreased as impact velocity increased. Surface geometry also significantly affected force attenuation ($F(7,64) = 294.32$; $p < .0001$; Figure 3). Furthermore, there was a significant interaction

Table 1. Patient demographics and summary of results from user testing in acute care.

Patient	Age (years)	Reason for admission	Number of days of wearing stick-on hip protector	Nurse comments
A	90	Right tibia fracture	7	No side effects Patient commented once on night-time discomfort, so only wore the protectors during the day
B	91	Right hip fracture	7	No side effects No discomfort complaints
C	87	Failure to thrive	5[a]	No side effects No discomfort complaints
D	82	Right hip fracture	7	No side effects Patient complained of stiffness in the right hip and of discomfort due to the protector Patient had previously worn garment-based protectors
E	79	Left tibia fracture	7	No discomfort complaints Hip protectors lost adhesion and fell off easily
F	76	Confusion	0	Patient had previously refused garment-based hip protectors

[a]Patient discharged from the hospital after five days; participation was terminated at this point.

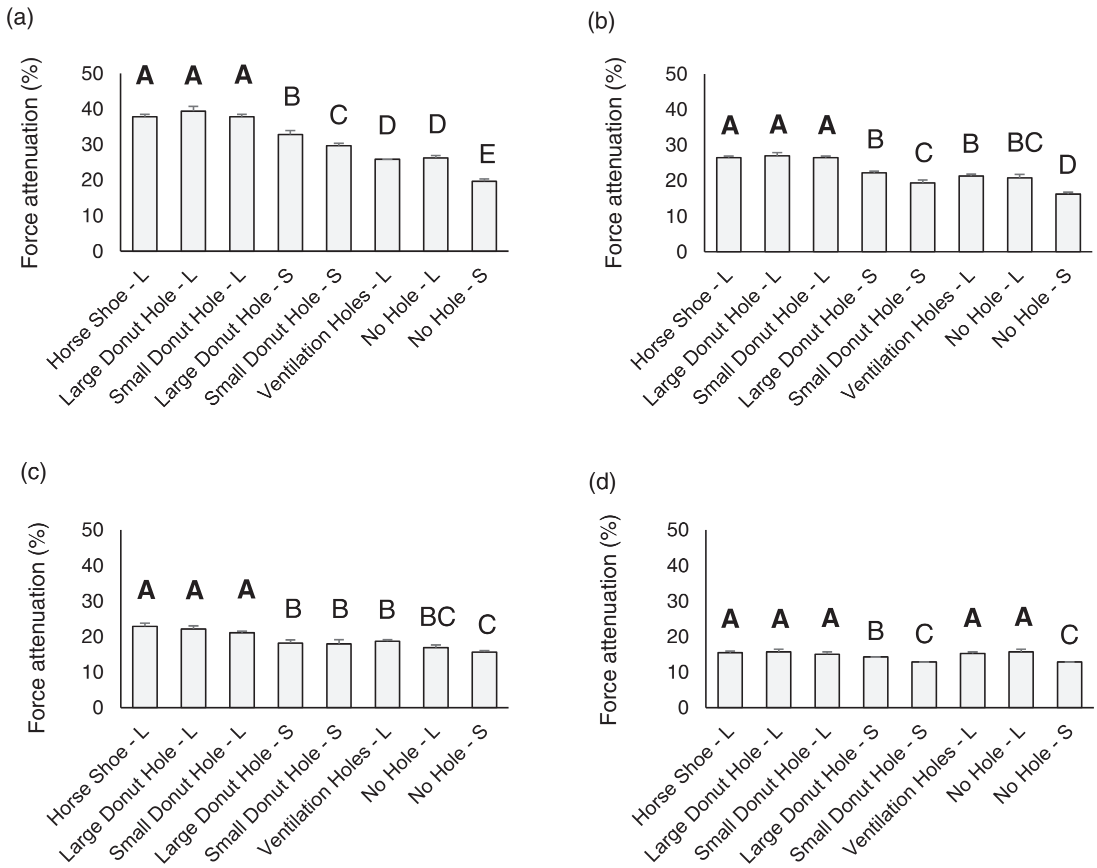

Figure 3. Effect of hip protector geometry and impact velocity on force attenuation. Bars and error-bars represent the mean + 1SD of the three trials for the given protector and impact velocity. Post hoc pairwise comparisons between protectors, at each impact velocity, are represented by the letters above the bars. Comparisons between protectors that did not reveal statistically significant differences are indicated by the same letter. (a) Impact velocity 2.0 m/s, (b) impact velocity 3.0 m/s, (c) impact velocity 3.4 m/s, and (d) impact velocity 4.0 m/s.

between surface geometry and impact velocity on force attenuation ($F(21,64) = 47.24$; $p < .0001$). Of note, the influence of surface geometry on force attenuation was weakened as impact velocity increased: mean force attenuation for individual protectors ranged from 20% (small, no-hole protector) to 39% (large donut hole) when the impact velocity was 2.0 m/s, though only ranged from 13 to 16% when the impact velocity was 4.0 m/s (Figure 3).

With regard to individual protector performance, the horse shoe pad and the 19×5.5 cm donut-hole pads (both large-hole and small-hole) attenuated significantly more force than the smaller pads, the no-hole pads, and the ventilation-hole pads, when tested at or below an impact velocity of 3.4 m/s (pairwise p values $\leq .002$; Figure 3). We found no statistically significant differences in force attenuation between the three highest-performing pads, for each of the four impact velocities (pairwise p values $\geq .3$; Figure 3).

As the large donut hole pad provided a continuous surface that better resisted "catching" on incontinence products than did the horseshoe model (a concern identified in our user testing in acute care), and used less material than the small-donut-hole pad, it was selected in exploring the effect of pad thickness on force attenuation.

Influence of pad thickness and surface area (select, high-performing protectors). For the large donut hole pads, force attenuation increased significantly with pad thickness ($F(2,12) = 348.19$; $p < .0001$) and was significantly higher for the 19×5.5 cm pads than for the 17×3.5 cm pads ($F(1,12) = 312.51$; $p < .0001$). Pad thickness and surface geometry did not interact significantly ($F(2,12) = 2.86$; $p = .1$). Furthermore, post hoc pairwise comparisons revealed that force attenuation between the 16 and 20 mm thick pads and the 20 and 24 mm thick pads increased significantly with pad thickness (all pairwise p values $< .0001$). When 20 mm thick or greater, both pad geometries attenuated more force than both the "HipSaver" pads (21% force attenuation; 18 mm thick) and "Air-X" pads (20%

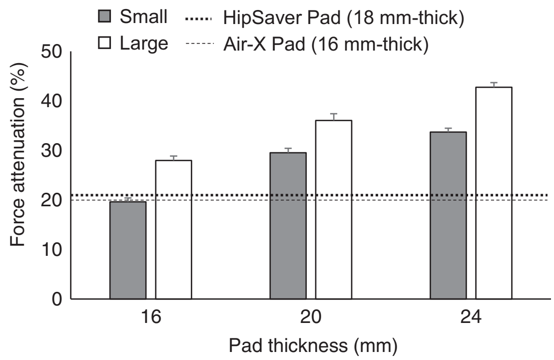

Figure 4. Effect of pad thickness and size on force attenuation, for the large donut hole pad. Bars and error-bars represent the mean + 1SD for the three trials, for the given pad thickness and size. Mean force attenuation values for the "HipSaver" Pad and the "Air-X" Pad are shown for comparison. At a pad thickness of 20 mm, both pad sizes attenuated more force than the garment-based commercial models. The impact velocity was 3.4 m/s.

force attenuation; 16 mm thick), with the large- and small-area, 20 mm thick stick-on pads attenuating 36 and 30% of impact force, respectively (Figure 4).

Feedback Fair with healthcare professionals

During the Feedback Fair, 43 healthcare professionals participated and completed questionnaires: 18 from Medicine, 22 from ACE, and three care staff who were part of multiple units. Participant positions (reported in the questionnaires) included Registered Nurse (n = 17), Student Nurse (n = 7), Licensed Practical Nurse (n = 4), Physio-Rehab Assistant (n = 3), Nursing Unit Clerk (n = 2), Occupational Therapist (n = 2), Patient Care Coordinator (n = 2), Physiotherapist (n = 2), Acute Health Care Worker (n = 1), Health Care Aide (n = 1), Home Health Liaison (n = 1), and Nurse Educator (n = 1).

Four notable themes of the Version 2 stick-on hip protector prototypes were identified from staff comments in the interactive posters, questionnaires, and field notes: (1) usability, (2) pad positioning and comfort, (3) cost, and (4) appearance.

Usability. Ease of use was the most common theme among clinical staff comments. A typical initial impression of the stick-on pad was that "it is easy to put on and I think will save us time." On the interactive posters, comments included "easy to use," "easy application," and "easy removal." Staff also commented repeatedly on how they felt that the stick-on hip protectors would improve patient toileting and patient independence, which they noted among common reasons for patient avoidance in wearing hip protectors. One Registered Nurse stated that the prototypes "avoid[s] specialized underwear that is hard to pull down and consequently facilitates incontinence." Others indicated that the stick-on hip protector prototypes will "promote easier toileting." One participant noted that the "best thing will be we don't need to take them off for the washroom."

Pad comfort and positioning. Staff were excited that the results from initial user testing suggested low discomfort among patients, and noted in interactive poster comments that the most common reasons in their acute care facilities for patients refusing to wear garment-based hip protectors were that they were "uncomfortable," "too tight," or "too hot." Further to this, several staff commented that the stick-on prototypes offered "decreased layers" (in that the stick-on prototypes can be worn without a second undergarment) and were "not baggy" or "not bulky." They also highlighted the challenges associated with ill-fitting garments, including "models that are too big end up around patients' knees and act as a tripping hazard, whereas models that are too small are difficult to remove for weaker patients, which result in losing their balance," or in exacerbating incontinence.

Staff also commented positively on the potential for the stick-on protector to stay in place, provided that the protectors remained "sticky enough." For example, one participant noted that the stick-on prototype was "more likely to stay on in the correct area, compared to the current underwear style – which, if the size is not correct, they shift."

Despite these benefits, staff expressed the need for more information, including data on the quality of adhesion to patients. Staff were concerned that the pads "may fall off easily," and expressed uncertainty over "how long will [the pad] stick," and if patients (particularly with dementia or confusion) could "pick them off." One participant commented, "I would like them to be trialed to see if our elderly population will be removing them." Despite the absence of evidence of skin irritation during our user testing, staff also expressed concerns that the "skin [was] not able to breathe" over longer durations, with one participant commenting that their "only concern could be if it worked for an extended period of time (i.e., 21 days), would skin integrity be compromised?". Another participant noted that the stick-on protector "may not be suitable for elderly patients with fragile skin." The issue of infection control was also raised, stemming from the possibility of "feces/urine sticking to the lining, causing skin problems."

Staff also remarked that a range of sizes would allow for better customization to individual anthropometry, noting that the sample stick-on models at the fair "may be too big for some of our more frail seniors."

Finally, staff commented that they were "unsure about the feel of the material on the skin, [which] may require some time to get used to for patients."

Cost. Staff commented positively on the potential for stick-on hip protectors to improve affordability, noting that they "avoid costly specialized underwear." However, a few staff members expressed their desire to see a cost effectiveness evaluation, with a physical therapist noting that "a cost comparison would be important and interesting in a larger-scale clinical trial to see if they would be less expensive in the long run."

Staff also liked that there was "no need to wash" stick-on hip protectors, which they noted as a common cause for misplacing and needing to replace garment-based protectors. For example, one Registered Nurse remarked that "you need [garment-based protectors] and they are not there – they never come back from the laundry." This comment was re-affirmed by other staff, who stated that garment-based "hip protectors are always wandering to other units."

A few staff members also noted the potential environmental cost related to stick-on hip protectors, remarking that the non-recyclable, disposable model was "a huge negative," and expressing concerns about amplifying waste in the hospital. In a sticky note on the "Dislike" poster, one participant commented "Waste! Especially if you have to replace multiple times a shift." Several professionals asked if they could "wipe the pads" down, potentially with anti-bacterial wipes, to re-use them, while others enquired about the possibility of a removable adhesive tape that would allow the pads to be re-used.

Appearance. Staff highlighted the importance of reducing visual signs that patients are wearing hip protectors, noting that "aesthetic reasons" were major barriers to patient willingness to wear them. To that end, staff recommended that the stick-on hip protectors be offered in "skin colors," thereby helping to minimize contrast with patient skin and reduce the protectors' visibility. One nursing student further proposed that "a lighter color might be better so [care staff] can see if there is dirt or blood on the pad."

Discussion

Specific types of hip protectors have been shown to reduce the risk for hip fracture in the event of a fall by up to 80%. However, the compliance of older adults in wearing typical garment-type hip protectors is low, especially in the high-risk hospital setting, where cost, ease of use in toileting, and laundering have been cited as barriers to uptake.[32] We describe results from three successive stages of development of a stick-on hip protector, designed to address the barriers to use of garment-based hip protectors in the acute care setting.

In the first stage, we assessed proof-of-concept by examining whether older adult hospital patients would wear an initial prototype (Version 1) of the stick-on hip protector, having a geometry that was modeled on an existing, soft-shell hip protector, and a skin-friendly adhesive. We found that five of six patients wore the stick-on hip protectors for the full week or for the duration of their hospital stay. We observed no adverse effects (including skin problems) related to wearing of the stick-on hip protector, although some patients mentioned discomfort in wearing the device, especially at night.

In the second stage, we refined the geometry of the hip protector through laboratory tests using a hip impact simulator that met international guidelines for biomechanical testing of hip protectors.[23] We found that a 20 mm thick donut-shaped (Version 2) stick-on hip protector provided more force attenuation than commercially available garment-based hip protectors ($\geq$30% versus 20–21% for Safehip and Hipsaver at 3.4 m/s). Accordingly, assuming equivalent or better patient compliance in wearing stick-on protectors, our Version 2 design should meet or exceed the protection provided by these garment-based products.

We found that force attenuation was greatest for pads that had larger surface area (19×15.5 cm), larger thickness, and a gap in the center portion of the pad (horseshoe or donut-shaped) which provided a bridge over the bone. While more research is needed to identify the largest thickness pad that individuals are willing to wear, we regard the 20 mm thick pad (which is very close to the 18 mm thickness of Hipsaver) as providing a reasonable balance between protective value and user acceptability.

We found that the large donut-shaped or horseshoe-shaped pads were among the top performing for force attenuation in each of the four impact velocities we examined. These ranged from 2.0 m/s, which matches the mean impact velocity of the pelvis measured from analysis of video footage of real-life falls in older adults,[25] to 4.0 m/s, which represents a severe fall. We also found that certain hip protectors provided more than twice the magnitude of force attenuation at 2.0 m/s than at 4.0 m/s. Furthermore, the differences in force attenuation across the eight 16 mm thick pad geometries decreased as impact velocity increased. These trends may reflect the tendency for the foam used in all prototypes to "bottom-out" (increase in stiffness under high compression) at higher impact velocities. The reduced benefit of energy-shunting hip protector pad designs at high impact velocities has been previously reported.[16,26,33]

In the third stage of development, we conducted a Feedback Fair to solicit the opinions of health professionals on Version 2 of the stick-on hip protector, which incorporated the large donut-shaped surface geometry and 20 mm thickness. Participants emphasized "ease of use" as a potential benefit, related to the ability to secure the hip protector directly to the patient's skin, and elimination of the physical challenges of donning and doffing additional garments (particularly during toileting) for both patients and care providers.[34,35] Participants also commented on the benefits of improved affordability and elimination of the need for laundering, two established barriers to user compliance with garment-based hip protectors.[13,18,36]

Participants in the Feedback Fair also commented on concerns related to breathability, skin side effects, and environmental impact of the stick-on protector. While skin problems were not noted for any of the patients who wore the device for up to seven days during stage 1, additional testing is needed to examine whether these trends persist in a larger sample who wear the device for a longer period. Additional research is also required to determine the cost effectiveness and the frequency of replacing stick-on versus garment-based hip protectors in the hospital environment, as well as to investigate the use of environmentally friendly materials and potential for re-use of stick-on hip protectors (e.g., by providing patients with replacement adhesives, and methods for cleaning the pads).

Our study has several strengths. We contribute evidence on the practicality of stick-on hip protectors in the acute care environment based on the willingness of older adult hospital patients to wear Version 1 of the stick-on hip protector. We also provide evidence from biomechanical testing using internationally accepted guidelines, which shows that the stick-on hip protector provides more force attenuation than garment-based hip protectors that are commonly used in Fraser Health hospitals (Safehip and Hipsaver). Furthermore, we describe the perceptions of care providers on Version 2 of the stick-on hip protector, including enthusiasm for improved ease of use, elimination of laundering, and cost saving when compared to garment-based hip protectors, and concerns regarding breathability, skin problems, and environmental impact.

Our study also had important limitations. With regard to user testing (stage 1), four of the five hospital patients who wore the stick-on hip protector were admitted for hip or lower-limb fractures. This may have increased their commitment to wearing hip protectors, when compared to older adults who had not previously sustained fractures.[13] Patient experiences were examined only for Version 1 of the pad, and additional testing with Version 2 is required to understand patient experiences during use, among a more diverse patient population, who wear the product for longer than seven days. With regard to biomechanical testing (stage 2), we measured force attenuation under controlled conditions, with trained researchers securing the stick-on protector to a surrogate pelvis. The protective value of stick-on pads may differ in practice, and, as with garment-based hip protectors, may depend on whether they are positioned correctly (highlighting the need for clear instructions), or worn by individuals with different pelvic sizes and soft tissue stiffness.[37] Furthermore, we examined the effect of pad thickness on force attenuation for only the two donut-hole geometries, at a single impact velocity (the value of 3.4 m/s recommended by international guidelines[23]). This decision was based on (a) the observation from our first set of tests that, among the eight geometries examined, the donut-hole geometries consistently ranked among the top performing, for each of the four impact velocities; and (b) the expectation that changes in thickness would not affect the relative rankings between products. This assumption was shown to be true in our second set of tests, where the large donut hole pad outperformed the small donut-hole pad for each of the three thicknesses examined. Finally, our findings apply to the products we tested, which were all formed from polymeric foam having a hardness of approximately 60 durometer, which has been shown to provide better force attenuation than softer or harder materials.[20] Pads based on other materials may differ in their protective ability and in user perceptions of wearability.[20,26]

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: FF and SNR have acted as consultants to Blue Tree Medical for the design and biomechanical testing of hip protectors. SNR has also consulted for Tytex A/S in the design and biomechanical testing of hip protectors.

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Guarantor

SNR.

Contributorship

SNR, FF, EP, JS-G, and AMBK conceived the study, researched literature, and gained ethical approval. EP performed data collection. EP and VK performed data analysis and took lead roles in writing the manuscript. SNR, FF, EP, JS-G, and AMBK reviewed and edited the manuscript.

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