Durability and residual moisture effects on the mechanical properties of external hip protectors

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S.P. Applegarth, T. Bulat, S. Wilkinson, S.G. Fitzgerald, P. Quigley, S. Ahmed. Durability and residual moisture effects on the mechanical properties of external hip protectors. Gerontechnology 2009; 8(1):26-34; doi 10.4017/gt.2009.08.01.004.00. An investigation into the mechanical properties of two types of hip protectors, after repeated launderings, was conducted at the VISN 8 Patient Safety Center in Tampa, Florida. A hybrid soft/hard protector and a soft foam protector were used in this study. Both sets of hip protectors were washed and dried in increments of 25 laundering cycles and then impacted in the laboratory. Results indicated that there was a decrease in protective properties with the hybrid protector as the number of launderings increased. In addition, the dome shaped outer shell of this hybrid protector became significantly less pronounced which would allow the transmission of more of the impact force into the greater trochanter. The soft protectors began to show the same downward trend as the hybrid protectors but suddenly reversed when the experimental protocol was altered. These unusual results lead to further testing of the effects of residual moisture content inside soft foam protectors. Data from the subsequent impact tests indicated that indeed residual moisture does play an adverse role in a soft protector's ability to attenuate force. Results from these experiments should lead one to assure that hard shell protectors keep their protective shape and that soft foam protectors are adequately dried before use.

Keywords: hip protectors, durability, fall impacts, hip fracture, mechanical testing

Approximately one-third of adults over age 65 fall each year. Those living in institutions fall at three times that rate (1.5 falls per bed per year); as many as 25% of institutional falls result in fracture, laceration or need for hospital care[1-4]. The costs of fall related injuries for people age 65 and older is expected to reach $32.4 billion by 2020[5]. One of the most serious consequences of a fall is a hip fracture. In most cases, the immediate cause of hip fracture is a lateral fall with direct impact on the greater trochanter of the proximal femur[6]. Hip fractures are associated with a host of negative outcomes for patients including increased hospitalization, institutionalization, and mortality, especially in men[7-11]. One study found the odds of dying double when hip fractures are coupled with cardiac, neoplastic or cerebrovascular diseases[12]. Evidence of hip protector effectiveness is currently mixed[13], and it somewhat supports their use only in long-term care facilities[14]. A possible explanation for contradictory results might be related to adherence with their use, as well as durability issues, which was the target of the current study. To date, only new, unused hip protectors have been mechanically examined, leaving clinical concerns related to the impact of repeated lateral falls and repeated laundering unanswered. The authors questioned if the protective properties of hip protectors would change after prolonged use and exposure to repeated washings/dryings (high frequency rotation, press drying, powerful chemicals). Answering this question would assist clinicians' decisions related to the number and frequency of prescriptions needed for safe and effective hip protector use. A study was designed to test the biomechanical properties of two types of hip protectors. The tests would consist of mechanically impacting the hip protectors after they had been put through a typical laundering process. For the purpose of this study the two brands of hip protectors selected were based on testing completed in a previous study in the author's lab[15]. The protectors that were selected were a soft hip protector and a hybrid type hip protector. Both are commercially available in the United States. The hybrid protector is composed of a domed, hard plastic shell with an apparent closed cell foam backing layer, while the soft protector was comprised of apparent open cell foam encased inside a sealed plastic covering. Each manufacturer has proprietary rights over their product therefore it was impossible to determine exact product compositions. The study consisted of two phases; in Phase I the hip protector pads were laundered up to 125 cycles and impacted after 25 cycles. Based on the findings from Phase I, it was necessary to conduct a Phase II study that evaluated the effect of moisture on the protective properties of soft hip protectors only.

Methods

Impact experiments

Testing System

The methods used for the impact experiments have been described elsewhere[15]. Laboratory testing in this study can be considered slightly different from that found in other impact studies that use mass-spring or pendulum type impact systems. However, it is felt that the testing protocol presented here produces relatively consistent results when compared to other studies.

All of the impact experiments in this study were conducted on an INSTRON DYNATUP 9250 HV vertical impact-testing tower. The weighted crosshead of this machine can be raised to any desired height, and then released resulting is a controlled impact scenario. The experimental setup was fully instrumented, with all sensors interfaced to a PC-based automated system for performing graphical and numerical analysis. The entire apparatus was calibrated using a software correction algorithm to compensate for the effect of losses (friction, wind resistance, etc.) and to make adjustments to the raw velocity data sent from the sensors. The crosshead was precisely weighed between each experiment to guarantee the accurate computation of energy values from gathered force data.

An impact striker was custom made in the laboratory to closely simulate the impact area of the head of the greater trochanter found in the average adult. The head of the striker protruded through a flat plate jig that held each hip protector in place. A concrete block with a linoleum tile overlay was chosen for the impact surface as a type of flooring most commonly used in hospital/healthcare settings.

A 4,450 N piezoelectric load cell was used to acquire the force data. The load cell was positioned right behind the impact striker and provided force data that directly correspond to the loads passing through each protector and into the hipbone.

Polyethylene foam sheets measuring 152 mm x 152 mm x 5 mm were used to simulate the soft tissues covering the greater trochanter[15]. These sheets were placed between the backside of the hip protector and the simulated hip bone, and a new layer was used after each subsequent impact.

Testing parameters

The baseline hip fracture force used in this study was 3,100 N, which is considered to be the average force needed to break the proximal femur of elderly women with a mean age of 71 years[17]. This force can vary greatly from person to person based on many factors including bone structure and the dynamics of the fall scenario. An external impact force of 17,000 N was chosen based on the force data recorded in a study involving instrumented human subjects during actual falls[16]. To attain this desired impact force, a second 22,000 N piezoelectric load cell was placed on the impact surface. The weighted crosshead of the impact machine was then dropped, without a hip protector, from incrementally increasing heights until the desired impact force was obtained. The final parameters obtained for these impact experiments were a crosshead mass of 8 kg and a drop height of 0.33 m.

Laundering durability testing

Laundering protocol

Each brand of hip protector was separated into 8 batches consisting of 10 pairs. The sample size is based on results from a previous study of repeated impacts, and gives an 80% power at significance level of 0.05 (two tailed) to detect a medium effect size[13]. Multiple batches of hip protectors were used in this study to avoid the effects of erroneous data produced from multiple impacts (cumulative fatigue). Therefore, each batch of hip protectors was laundered the appropriate amount of times and impacted just once. Each batch of protectors was laundered (1 wash + 1 dry) in increments of 25 cycles with the goal of reaching 125 total cycles (chosen arbitrarily, based on the available funding for the study). A typical washing detergent was used (Ultra with bleach, distributed by Wal-Mart, Inc.) and all attached washing instructions were adhered to during the laundering process. The washings/dryings were performed in a Laundromat facility for commercial use by individuals. A standard hot water cycle (exact temperature was not measured, 60°C as per Laundromat facility) and water supplied by the city of Tampa were used for the washing process. The exact water hardness was not measured. However, the average hardness of Tampa city water is 250 ppm. The drying cycle was a standard 16 minute drying cycle (no temperature available) and no drying conditioner was used.

Impact testing procedure

All of the hip protector pads were cut away from their respective garments to avoid interference within the testing machine, but still remained surrounded by their fabric outer layers. The polyethylene foam layer (to simulate soft tissue) was added between the protector and the impact striker. A protector-positioning jig was created to properly align the pads on the testing plate, assuring that each protector was placed in the same location. Each protector was securely held in place with elastic fastening ties (*Figure 1*). Impact testing was conducted in a laboratory environment under normal atmospheric conditions (22°C, humidity not measured).

RESULTS PHASE I

Changes in durability of the outer garment (fabric, stitching, Velcro) were assessed using visual inspection after every laundering cycle.

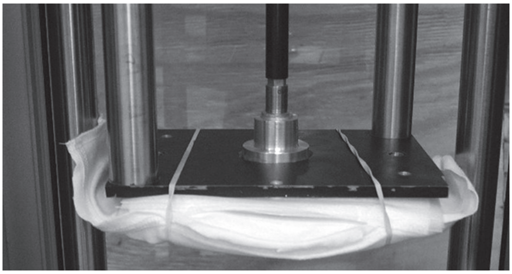

Figure 1. Hip Protector attached to impact machine

Minor changes were noted on both types of protectors but none significant enough to be a concern or a reason to discontinue wear. Different force attenuation responses were obtained from the two different types of hip protector used in the laundering study and are presented below.

Hybrid protectors

The data collected from the hybrid protectors indicates that the pads protective properties can deteriorate over multiple laundering cycles. The mean force, reaching the hipbone, increases with multiple laundering cycles (*Figure 2*). The pads studied showed a 137% increase in the mean force passing into the hipbone after 100 laundering cycles. A dramatic 61% increase in force was noticed directly after the first cycle of 25 launderings. An increase in standard deviation with laundering cycles was also observed.

Several pads exhibited unusual signs of deterioration in that the fabric stretched over the plastic shell became abnormally tight. These specific pads also appeared to have a less pronounced dome structure formed by the rigid shell. These pads produced extremely high force readings, greater than the 4,450 N load cell could accurately and safely measure. Therefore, once a pad was identified as possessing these unfavorable traits, it was not impact tested to protect the load cell from damage. Upon further inspection, it was found that the chemical bonding agent used to hold the foam pad to the hard shell had been compromised and thus the foam pad was pushing against the interior of the fabric garment. The occurrence of these pads increased with laundering cycles, so it is conceivable that the average force data presented may underestimate the true extent of deterioration experienced.

Laundering, for the hybrid protectors, stopped after 100 cycles due to the large number of pads that were exceeding the imposed hip fracture threshold of 3,100 N. The final cycle produced a mean force of 3,296 N with 8 out of 17 pads (nearly 50%) exceeding the hip fracture threshold of 3,100N.

Soft foam protectors

The soft foam hip protectors produced some counter-intuitive and intriguing results. Figure 3 depicts the mean force passing through the pads. The mean force, observed by the hipbone, showed indications that it was increasing due to laundering with the mean force increasing by 168% from 0 laundering cycles to 75 cycles. Suddenly, at the 100-cycle mark the trend appeared to be reversing as the mean force started to drop. This curious trend continued as the 125 laundering cycle batch produced a mean force 57% lower than the 75 cycle batch and only 16% higher than the control batch.

Upon further investigation into these findings, it was found that a delay in the testing protocol had occurred (due to lab closings during a particularly active hurricane season) which allowed extended drying times for the soft protectors. Based upon this discovery it was hypothesized that the soft hip protector impact properties may be dependant upon

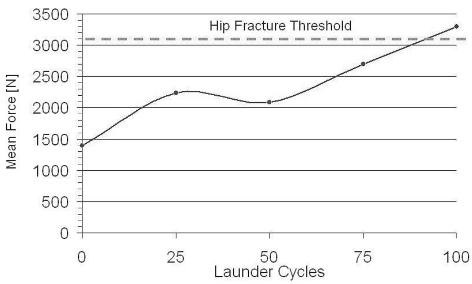

Figure 2. Mean force measured [N] for the hybrid hip protectors vs. number of laundering cycles

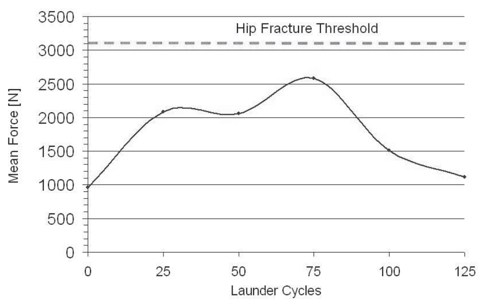

Figure 3. Mean force measured [N] for the soft foam hip protectors vs. number of laundering cycles

trapped moisture content within the foam pad material. Considering this unusual trend was only observed in the soft pads, possibly due to the different composition foam, a detailed moisture analysis was not conducted on the hybrid protectors.

Moisture testing

Several studies have been conducted investigating the force attenuating properties of hip protectors[15-19]. However, none of these studies have ever examined the effects of moisture on a hip protectors ability to attenuate (shunt or absorb) impact force. As an incompressible fluid, water would act as a direct pathway for force/energy to pass into the body.

Moisture penetration analysis

An experiment was conducted that examined if moisture penetration into the soft foam pads could have a negative effect on the protective properties of the soft foam pads.

To carry out this phase of the experiment, seven randomly selected new hip protector pads were carefully cut away from their garment fabric. Cutting the fabric along the stitching line allowed each pad to be extracted without damaging the external protective plastic cover surrounding the foam core.

After removing the fabric covering, pads were then submerged to a depth of six inches in a 53 liter tank of water containing a soap solution in order to more accurately reproduce actual washing conditions. The pads were removed one at a time for periods ranging from 6 to 47 hours which corresponded to lab staffing times. The seventh pad was used as the baseline control with zero hours of submersion. After exposing the internal foam, moisture levels were checked with a DELMHORST BD-2100 moisture meter at various locations within the pad and then averaged. This type of meter is used to measure moisture levels, in percent of moisture present, in more porous materials such as foams and insulation materials. The meter was calibrated to read 0% if no moisture was present in a sample, and 100% if completely saturated with water. Moisture levels relative to these set reference points (0, 100) were then measured and recorded. Since this meter uses two protruding pins to pierce samples, the effects of atmospheric humidity on the readings were considered negligible.

The results from this preliminary investigation revealed that moisture could penetrate through the protective enclosures and into the foam pad. Figure 4 depicts the average moisture levels for pads vs. time submerged. It is evident that as submersion time increases so does the corresponding moisture content within the pad.

Having concluded that moisture can penetrate into the foam pads through submersion in water, it was decided to evaluate the effect of increasing drying time on the protective properties of soft foam hip protectors.

Laundering protocol

The protocol was strict and controlled to assure that laundering and handling were standardized. The major factors that were considered crucial in standardization included: (i) Using the same washer & hot water wash cycle, (ii) Using the same dryer & dry cycle (hot, 16 minutes/cycle), (iii) Using the same amount of washing detergent, (iv) Hip protectors were kept in a tightly sealed plastic bag until the time of testing, and (v) Hip protectors were stored in the same climate controlled location between cycles.

Ten pairs of new hip protectors (20 protector pads in total) were separated into five

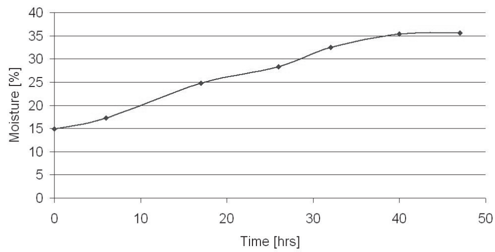

Figure 4. Average moisture content vs. time for foam hip protectors

Table 1. Moisture and force data of the control (no wash / no dry) and after 10 wash/dry cycles and different extra drying cycles

Measurement	**Control**	**Number of extra drying cycles**			
		None	**1**	**2**	**3**
Mean Force N	1319.00	1496.87	1777.54	1511.97	1153.28
Mean Moisture %	12.13	18.25	18.61	16.83	9.22

batches. Four of these batches were laundered while the remaining batch was used as the baseline control group. One complete laundering sequence is considered a wash cycle followed by a drying cycle. The laundering protocol consisted of a 4-week regimen where the number of washings remained constant but the number of dryings increased by one from the previous week. Each batch of protectors was washed ten times however; as the weeks progressed an additional dry cycle was added to complete the sequence i.e.
Week 1: 10 washes + 10 dryings
Week 2: 10 washes + 11 dryings
Week 3: 10 washes + 12 dryings
Week 4: 10 washes + 13 dryings

Moisture analysis
The hip protectors were kept in a sealed plastic bag during transport and storage prior to laboratory testing. Each hip protector pad was then placed into the impact machine and impacted using the process mentioned previously (mass, height, skin, etc.). Each pad was then cut out of the garment fabric and plastic film enclosure, completely exposing the interior foam. The moisture meter was inserted into each pad at the five different locations. Each of the five readings was recorded and the mean was used in assessing the moisture level of each pad. Comparisons across the mean moisture level of each batch where compared using a one-way ANOVA.

Results phase II

The results from Phase II of the study are presented in Table 1. Data from Batch 1, when compared to the control, clearly indicates that additional moisture passed through all the covering layers and into the foam padding. The corresponding force values also show a rise from the control to Batch 1. With only 1 additional dry cycle applied to Batch 2, no significant difference can be seen in moisture content. However, Batch 3, which has 2 extra dry cycles, is significantly drier than the previous laundered batches and has a mean force value below that of Batch 2.

Moisture levels of the control batch were significantly different ($p<0.001$) than all other batches, with batches 1, 2 and 3 having higher mean moisture values. Batch 4, though, had significantly less ($p<0.001$) moisture than the control batch. Batch 4, which was given 3 extra dry cycles, is by far the driest batch of protectors measured (even surpassing the control). Not only were these batch of protectors the driest, they also protected the best by allowing the least amount of force into the hipbone. Figure 5 shows the performance trends of the pads over the study period. This plot shows a trend of the pads performing better (less force) when they are sufficiently dried. The scatter of force values (standard deviation) also decreases with lower moisture levels.

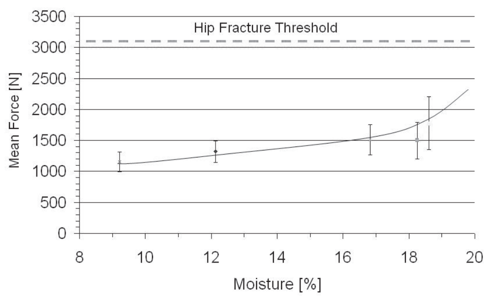

Figure 5. Mean force measured vs. moisture content

Discussion

The results from Phase I of this study clearly showed that the hybrid hip protectors deteriorated with multiple laundering cycles. This was supported by the measured force results and by a visual inspection of the protectors prior to impact. The initial reasoning behind this phenomenon suggests that repeated laundering cycles tend to flatten out the plastic shell covering the hip. Most of the pads force shunting ability is lost when this shell begins to lose its rigid dome shape. The force that was once directed around the susceptible areas on the body is now allowed to pass directly through the pad and into the hipbone. Additionally, several of the hybrid protectors suffered adhesion failures when the foam pad became separated from the rigid shell as launderings (which includes drying cycles) progressed. This adhesion failure was no doubt not intended and thus altered the product from its original state.

The soft foam hip protectors posed numerous and intriguing questions during the study. Initially, the pads behaved much like the hybrid protectors, allowing more force through the pad with multiple washings. However, at laundering cycle 100 began the unusual trend of the pads actually performing better (transmitting less force into the hipbone). This curious trend continued through laundering cycle 125, which produced a mean force close to the initial unlaundered control group. The subsequent inquiry into this problem identified that a delay in testing had occurred over this interval which led to additional drying time for the protectors. A hypothesis was made that moisture, from the laundering cycles, was able to pass into the foam pad and contribute to the transmittal of force into the hipbone. This hypothesis was only applied to the soft foam protectors as they attenuate force solely by means of an open celled foam pad as opposed to the hybrid protectors, which relies predominantly on a hard plastic shell to shunt force around the hip. It should be noted that there was no measuring or fixed control of laboratory humidity levels during the impact experiments. Varying humidity levels during testing may account for the simultaneous drop in force for the soft and hybrid protectors at the 50 laundering cycle. It is recommended that future impact tests be conducted with more stringent controls on humidity levels. However, the results presented here are still significant as each batch of hip protectors were subjected to the same testing conditions and thus can be compared directly.

Phase II of the study focused on subjecting additional dry cycles to each batch of soft hip protectors. The results from this phase of the study showed there is a trend for the soft protectors to improve their force attenuating properties the drier they become. Data collected indicates that it is possible to have a pad perform better than when shipped from the factory even after 100 wash cycles (Batch 4). This evidence strongly suggests that if given enough energy and/or time to dry the pads sufficiently, they will indeed perform better. It is believed that the moisture is forced into the pad through the heating and mechanical agitation experienced during the laundering process. Residual moisture remains 'trapped' inside the foam once removed from these stimuli. It is felt that minor fluid spills or normal amounts of sweat would not have much influence on the protective properties of these soft protectors. These occasional small scale fluid interactions would have a hard time penetrating both the fabric outer layer and the sealed foam casing under normal daily use.

Conclusion

Until this study, it was unknown if the protective properties of hip protectors change with regular laundering. Data collected indicates that hybrid hip protectors behave very differently when compared to soft foam hip protectors during repeated laundering cycles. Hybrid hip protectors progressively lost their protective properties with repeated laundering cycles. The hypothesis for this deterioration is given to the fact that the hard protective shell tends to lose its dome shape with multiple laundering cycles as well as suffering from interior adhesion failures. It is essential that this dome shell retain its prominent shape and not suffer from pad/shell separation in order for these types of hip protectors to function properly. A recent study[20] found a similar hybrid hip protector not to be effective for hip fracture prevention. A possible explanation for these results can be found in this current laundering study: the hybrid hip protectors lost their protective properties over time since no replacement protocol existed.

The data indicates that the soft foam hip protectors' energy attenuation properties were not affected by repeated laundering (up to 125 cycles), but rather the amount of moisture retained in the pad after the laundering cycle. The moisture levels found in the pads were measurable but not considered substantial enough to actually have a 'flowing' mechanism associated them. Therefore it is unlikely that the moisture in the pad would migrate to other portions of the pad over time. Benefits from these soft types of protective garments may be enhanced by means of protocols aimed at extended drying processes. While the soft protectors seem to lose some of their abilities to attenuate force with additional moisture, the mean forces experienced by the simulated trochanter were still below the hip fracture threshold used in this experiment of 3,100 N.

This study investigated only two types of hip protectors therefore it would be imprudent to assume that all types and brands of hip protectors would suffer from these same issues. However, it is still recommended that all types and brands of hip protectors are checked after every laundering cycle to ensure that they have no signs of deterioration, are adequately dry, and that they retain their normal exterior shape. The data presented in this paper also lends credence to the adoption of a laundering testing protocol within a hip protector testing standard that is critically needed.

Acknowledgements

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References

1. Rubenstein L, Josephson K, Robbins A. Falls in the nursing home. Annals of Internal Medicine 1994;121(6):442-451
2. Doweiko D. Prevention Program Cut Patient Falls by 10%. Hospital case management 2000;8(38):43-44
3. Rubenstein L, Powers C, MacLean C. Quality indicators for the management and prevention of falls and mobility problems in vulnerable elders. Annals of Internal Medicine 2001;135(8):686-693
4. Hoskin A. Fatal Falls: Trends and characteristics. Statistical Bulletin 1998;79(2)10-15
5. Englander F, Hodson TJ, Terregrossa RA. Economic dimensions of slip and fall Injuries. Journal of Forensic Science 1996;41(5):733-746
6. Greenspan SL, Myers ER, Kiel DP, Parker RA, Hayes WC, Resnick NM. Fall direction, bone mineral density, and function: Risk factors for hip fracture in frail nursing home elderly. American Journal of Medicine 1998;104(6):539-545; doi:10.1016/S0002-9343(98)00115-6
7. Braithwaite RS, Nananda F, Wong JB. Estimating hip fracture morbidity, mortality and costs. Journal of the American Geriatric Society 2003;51(3):364-370; doi:10.1046/j.1532-5415.2003.51110.x
8. Forsen L, Sogaard AJ, Meyer HE, Edna T, Kopjar B. Survival after hip fracture: short and long-term excess mortality according to age and gender. Osteoporosis International 1999;10(1):73-78; doi:10.1007/s001980050197
9. Marottoli RA, Berkamn LF, Summers L, Cooney LM Jr. Predictors of mortality and institutionalization after hip fracture: the New Have EPESE cohort. American Journal of Public Health 1994;84(11):1807-1812
10. Wolinsky FD, Fitzgerald JF, Stump TE. The effect of hip fracture mortality, hospitalization and functional status: a prospective study. American Journal of Public Health 1997;87(3):398-403; doi:10.2105/AJPH.87.3.398
11. Fransen M, Woodward M, Norton R, Robinson E, Butler M, Campbell J. Excess mortality or institutionalization after

hip fracture: Men are at greater risk than women. Journal of the American Geriatrics Society 2002;50(4):685-690; doi:10.1046/j.1532-5415.2002.50163.x

12. Myers AH, Robinson EG, Van Natta ML, Michelson JD, Collins K, Baker SP. Hip fractures among the elderly: Factors associated with in-hospital mortality. American Journal of Epidemiology 1991;134(10):1128-1137
13. Parker MJ, Gillespie WJ, Gillespie LD. Effectiveness of hip protectors for preventing hip fractures in elderly people: systematic review. BMJ 2006;332(7541):571-574; doi:10.1136/bmj.38753.375324.7C
14. Sawka AM, Boulos P, Beattie K, Thabane L, Papaioannou A, Gafni A, Cranney A, Zytaruk N, Hanley DA, Adachi JD. Do hip protectors decrease the risk of hip fracture in institutional and community-dwelling elderly? A systematic review and meta-analysis of randomized controlled trails. Osteoporos International 2005;16(12):1461-1474
15. Bulat T, Applegarth S, Wilkinson S, Fitzgerald S, Ahmed, S, Quigley P. The effect of multiple impacts on protective properties of external hip protectors. Clinical Interventions in Aging 2008;3(3):567-571
16. Weiner SL, Andersson GBJ, Nyhus LM, Czech J. Force reduction by an external hip protector on the human hip after falls. Clinical Orthopaedics and Related Research 2002;398(May):157-168; doi:10.1097/00003086-200205000-00023
17. Kannus P, Parkkari J, Poutala J. Comparison of force attenuation properties of four different hip protectors under simulated falling conditions in the elderly: An in vitro biomechanical study. Bone 1999;25(2):229-235; doi:10.1016/S8756-3282(99)00154-4
18. Nabhani F, Bamford J. Mechanical testing of hip protectors. Journal of Materials Processing Technology 2002;124(3):311-318; doi:10.1016/S0924-0136(02)00200-5
19. Parkkari J, Kannus P, Heikkila J, Poutala J, Heinonen A, Sievanen H, Vuori I. Impact experiments of an external hip protector in young volunteers. Calcified Tissue International 1997;60(4):354-357; doi:10.1007/s002239900242
20. Kiel DP, Magaziner J, Zimmerman S, Ball L, Barton BA, Brown KM, Stone JP, Dewkett D, Birge SJ. Efficacy of a hip protector to prevent hip fracture in nursing home residents. The HIP PRO Randomized controlled trial. Journal of the American Medical Association 2007;298(4):413-422; doi:10.1001/jama.298.4.413