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ORIGINAL ARTICLE

Biomechanical testing of hip protectors following the Canadian Standards Association express document

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Abstract

Summary A variety of hip protectors are available, but it is not clear which is the most effective and there is no standard test to evaluate their performance. This is the first study that uses a standard mechanical test on hip protectors. Some protectors perform well but others are almost ineffective, providing little to no protection to the wearer during a fall.

Introduction Each year, over 70,000 patients are admitted to hospital in the UK with hip fractures. There are a variety of commercial hip protectors currently available. However, it is not explicitly clear which is the most effective with regard to maximum force attenuation, whilst still being both comfortable for the user and providing reasonable force reduction if misplaced from the intended position. The numerous test methods reported in the literature have given conflicting results, making objective comparison difficult for users, researchers, and manufacturers alike. The Canadian Standards Association (CSA) has therefore published an express document (EXP-08-17) with a draft standard test method. This paper presents initial results for a range of hip protectors.

Methods Eighteen commercially available hip protectors were tested according to EXP-08-17. Each hip protector was impacted five times in correct anatomical alignment over the greater trochanter and once at 50 mm displacements in the anterior, posterior, and lateral directions.

Results Considerable differences were identified between individual hip protectors in their ability to reduce impact forces on the femur (between 3% and 36% reduction in peak force). The performance was reduced when misplaced in many cases (maximum reduction only 20%).

Conclusions This is the first study that uses a standard mechanical test on hip protectors. Previous studies have used a variety of methods, making it difficult to interpret results. We hope that these results using a standard test method will facilitate the effective comparison of results, as well as providing useful data for clinicians, users, and purchasers.

Keywords Biomechanics · Elderly · Falls · Fall injuries · Hip fracture · Hip protectors

Introduction

Each year, over 70,000 patients are admitted to hospital in the UK with hip fracture because of a fall [1]. The majority of hip fractures are caused by a sideways fall (from standing) with direct impact on the greater trochanter of the proximal femur [2–4]. Older adults, aged 65 years and over, are at high risk of falls and hip fractures due to osteoporosis, osteopenia, or loss of coordination. In the UK alone, osteoporosis is reported to affect more than 2.5 million people, with 500,000 cases receiving hospital treatment for fragility fractures (fractures that occur from standing height or less) annually [5, 6]. Worldwide, osteoporosis causes more than 8.9 million fractures per annum, resulting in an osteoporotic fracture every 3 seconds [7]. Women are more susceptible to osteoporosis because bone loss becomes more rapid for several years after menopause, when sex hormone levels decrease. Nearly 75% of all hip fractures occur in women [8].

The annual health care cost for all UK hip fractures is estimated to be £2 billion [9]. The World Health Organisation has estimated that between 2015 and 2050, the number of people aged 60 years and older will increase from 900 million to 2 billion (worldwide). With an ever-ageing

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population, demographic projections indicate that the UK annual incidence of hip fracture will rise to more than 100,000 by 2033 [10–12]. There is therefore an increasing need to discover a preventative solution for hip fractures in order to improve patient quality of life and reduce health care costs.

One method for preventing hip fracture is a specially designed external hip protector that upon impact attenuates the peak force applied to the proximal femur. This is achieved by either forming a bridge over the trochanter to shunt the force of the fall to the surrounding soft tissues, which provide the necessary additional cushioning to reduce the impact force; or by adding a soft, compliant layer over the greater trochanter. There are thus two main types of hip protector designs that support these mechanisms: (1) hard, plastic shell-shaped protectors for force shunting and (2) soft shell (foam) protectors, which primarily reduce force and potentially provide better comfort to the wearer. Both types of protectors can be incorporated in to the pockets of custom-designed undergarments and can be worn by anyone at risk of falling.

Existing evidence in the literature regarding the clinical efficacy of hip protectors is controversial. Cochrane reviews in 2006 and 2014 found little convincing evidence that hip protectors are effective [13, 14]. A major problem is limited user compliance, resulting in a large number of falls and subsequent hip fractures occurring without any hip protection. A further difficulty is that some protectors may be incorrectly designed and offer little protection even when properly used, and so, there is a need for preclinical testing to assess their performance. Another issue is the effect of pad positioning when the hip protector is misplaced from the manufacturers intended position. A biomechanical study by Derler et al. found that the peak force at the femoral neck is increased by up to 23% when the pad is displaced by 30 mm in the anterior direction [15]. Several other studies have reported significant differences between individual hip protectors in their effectiveness to reduce the impact force on the femur when displaced up to 50 mm in the anterior, posterior and lateral directions [16, 17]. This further highlights the importance of a well-designed hip protector and well-fitting garments.

Previous biomechanical studies have reported a wide range of different values for peak femoral neck force attenuation between 3% and 89% [18–21]. Testing is typically carried out using either a pendulum design system or drop impact tower, but the conditions under which the methods are conducted (e.g. effective mass, impact velocity, pelvic stiffness, and geometry of the anatomical femur form) vary considerably between studies [15, 19, 22, 23]. Various techniques are also associated with the production of the anatomical femur form and soft tissue simulant, including silicone moulding, wrapping/layering foam, cutting/carving, and CNC machining [15, 19, 24–26].

Although there are a variety of commercially available hip protectors, it is not explicitly clear which is the most effective with regard to maximum force attenuation, whilst still being both comfortable for the user and providing reasonable force reduction if misplaced from the intended position. Until recently, no clear guidelines existed to ensure that manufacturers tested their products in the same manner. The numerous test methods reported in the literature have caused conflicting reports on the force attenuation provided by the hip protector, and as such have made objective comparison difficult for both researchers and manufacturers alike.

In 2007, the International Hip Protector Research Group (IHPRG) consolidated evidence-based recommendations that could be used for both mechanical testing of hip protectors and clinical trials [27, 28]. Since then, members of the group have regularly met via teleconference to further develop a consensus document about the biomechanical performance, selection, use, and care of a hip protector prior to being worn. In 2017, the Canadian Standards Association (CSA) published an express document, CSA EXP-08-17 Hip Protectors, as a first stage in standardising this test method [29].

This is the first study to test a variety of hip protectors using this test method. The aims of this study were (a) to compare the force attenuation of all hip protectors tested and (b) investigate the effect of pad positioning if misplaced from the intended position in accordance with the methods and values given in the document.

Test method

Test rig

Mechanical testing was performed according to the CSA EXP-08-17 Hip Protectors Documentation: where a mass of 28.0 kg is released vertically at a velocity of 3.2 m/s onto the hip protector [29]. A drop-weight test rig was used to impact the femur form during a simulated fall (Fig. 1). A load cell and oscilloscope were used to measure the peak force at the proximal femur. The temperature was recorded as 19.0 ± 0.5 °C throughout the test period.

Drop-weight assembly

Tests were performed using an Instron Dynatup 9250-HV (Instron, High Wycombe, UK) drop-weight rig. The total mass of the drop-weight assembly was 28.05 kg, where the heavy crosshead weighed 16.03 kg, the spring assembly 3.14 kg, and a series of weights that slotted in to the cross head assembly 8.88 kg. A spring with a stiffness of 40 kN/m is attached between the drop weight and the impact plate, which simulates the compliance of the human body. Based on

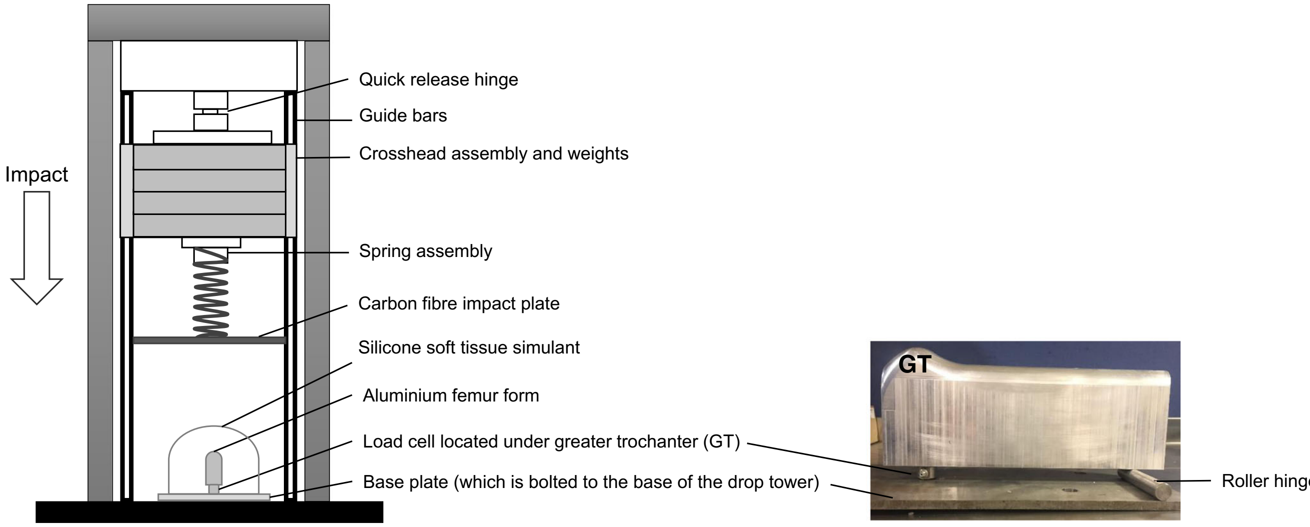

Fig. 1 Schematic of the Instron Dynatup 9250-HV and the experimental setup for measuring the peak compressive force applied to the proximal femur during a simulated sideways fall from standing height (CSA EXP-08-17)

extensive tests by Robinovitch et al. [27, 30], the distributed mass and compliance of the body are simulated by a smaller effective mass and a spring, which were shown to produce an equivalent impact response.

Impact plate

A rigid impact plate measuring 230 × 180 × 70 mm was made from carbon fibre. Notches were made on either side of the plate to account for the internal metal guide bars of the drop tower. Carbon fibre was chosen as a suitable material as it is strong (so can withstand repeated impacts) and light (which is necessary to minimise the unsprung mass that causes additional high frequency peaks in the impact response). The impact plate was regularly inspected for visual signs of damage. The impact plate remained the same for the duration of the testing period.

Anatomical femur form

The femur form was constructed from aluminium in order to resist repeated impacts. The length of the proximal femur was 250 mm, with a width of 30.0 mm and radius of 15.0 mm. The femur form was made by the mechanical workshop at Cardiff University. The piezoelectric load cell was screwed to the femur form and the base plate, which in turn is rigidly bolted to the base of the machine. For stability, the distal end of the femur is supported by a roller, which acts as a hinge (Fig. 1). Since the load cell is directly in the load path through the trochanter, it carries the load and there is a minimal force through the distal hinge, which is mainly to prevent accidental damage to the load cell.

Soft tissue covering

The silicone was cast in a custom-made mould created from polyurethane tooling board, glued together by low density epoxy paste Trelleborg EP579 (Fig. 2b). A sheet of polytetrafluoroethylene (PTFE) was used to cover the inside of the mould to ensure the silicone surface was smooth. An additional femur form was made for the mould, with two bars screwed on either end (Fig. 2a). This held the femur in the correct place, whilst the silicone was curing. The condensation cure silicone was then placed in the oven at 40 °C and left for 3 days to fully cure (Fig. 2c). The silicone soft tissue simulant covering the aluminium femur form was made using 80% RTV C204 silicone rubber, 5% by mass of 81b catalyst, and 10% silicone oil.

The surface dimension of the silicone was 200 mm in the anterior-posterior direction, with a radius of curvature of 115 mm. The length of the soft tissue covering in the superior-inferior direction was 300 mm, with the greater trochanter located at the centre point. The height of the soft tissue layer directly above the apex of the greater trochanter was 22 mm. Stiffness calibration tests were carried out on the silicone soft tissue simulant to ensure the femur form lay within the measured stiffness values of older women [21].

Calibration of the soft tissue covering

A Zwick Roell material testing machine was used to indent the soft tissue simulant quasi-statically under compression with a 3.8 cm diameter cylindrical probe. The soft tissue simulant was tested over the femur form (to simulate how it would be during testing), and a loading rate of 100 N/s was applied. A notch was cut in the side of the silicone to accommodate the

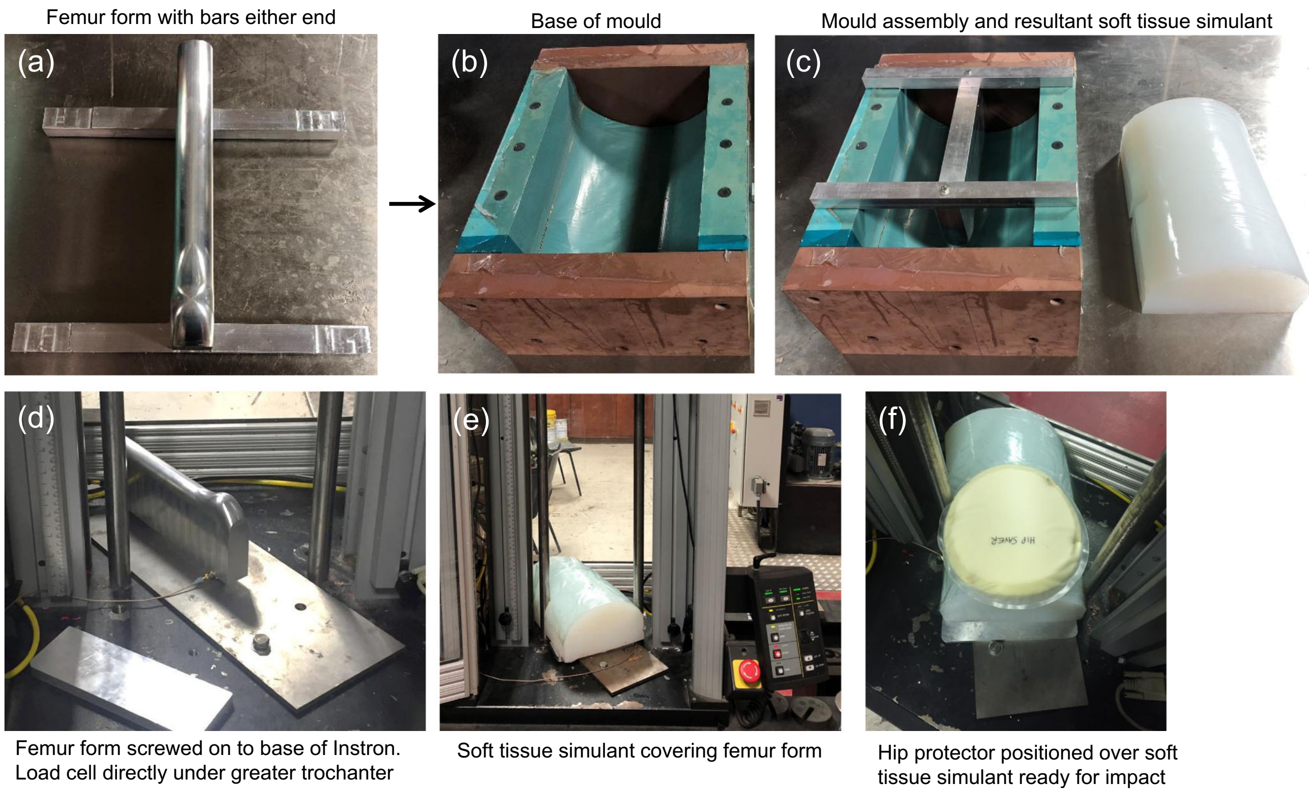

Fig. 2 Two-part assembly casting mould for silicone soft tissue simulant with resultant cured silicone (**a**–**c**). Setup of femur form screwed on to base of drop tower with soft tissue silicone and hip protector (**d**–**f**)

left hand side bar of the drop tower (Fig. 2e). This also ensured the soft tissue simulant lay flat whilst under impact.

Force measurement instrumentation

A piezoelectric load cell, type 9712B5000, 5000 Ibf (approximately 22.24 kN) maximum load by Kistler was located directly below the midpoint of the greater trochanter to support the femur form (Fig. 2d). The load cell was connected to an Agilent Technologies DSO1072B oscilloscope, 70 mHz, and 2 analog channels. The load cell was powered by a linear analogue, Farnell E30/1 bench power supply and set to 24 V throughout the testing period.

Baseline force measurements (dynamic calibration)

Three initial baseline force measurements were conducted and recorded prior to impacting the hip shields. The drop-weight assembly was dropped from a vertical height of 0.5 m onto the femur form (without a hip protector sample) to assess the peak force (Fig. 2e). The accepted range for the observed peak force is 2500 and 3000 N (Sect. A.4.1 of the CSA document). Further three baseline force measurements were taken throughout the testing procedure to ensure the baseline remained unchanged. This process was followed for both test I and test II, i.e. six baseline force measurements were conducted per test.

Hip protector samples

Eighteen different types of hip protectors were mechanically tested in this study (Fig. 3). Delloch provided all hip protectors currently sold in Australasia. Four of the eighteen hip protectors were bought direct from the manufacturer's website or from the UK online store, Amazon. Only one sample was tested per hip protector brand. Each hip protector was impacted five times in the centre position and once in the anterior, posterior, and lateral positions. The hip protectors tested were as follows:

1 × Delloch Flexi Shield—removable soft memory foam shield
1 × Delloch Active—removable closed cell foam shield
1 × Delloch Maxi ¾″ Shield—removable soft memory foam shield
1 × Delloch Closed Pocket ½″—soft memory foam shield sewn into garment male, XS*
1 × Delloch Slimline Closed Pocket—closed cell foam shield sewn into garment male, XL*
1 × Impactwear Active—soft foam shield sewn onto the outside of the underwear, M*

Fig. 3 Photograph showing top view of the 18 hip protectors tested

1 × Cubro Comfort Softech—removable closed cell foam shield (formerly Lyds), M
1 × Hip Saver Classic—removable memory foam shield, M
1 × Safehip Air X—removable foam shield, M
1 × Pelican Super Soft—removable closed cell foam shield
1 × Hornsby Comfy Hips—removable foam shield
1 × Bort—removable closed cell foam shield
1 × Suprima—removable closed cell foam shield
1 × Hipshield (Amazon UK)—female, M
1 × Hips (Amazon UK) —soft foam and flexible plastic male, S
1 × Fall-Safe Replacement Hip Protector (direct from website)—one size fits all
1 × Delloch Plus Shield, removable hard shield (test II only)
1 × Pelican Green—removable open cell foam shield (test II only)

*Note: For the hip shields supplied as part of a garment, the fabric was cut along the folded edges to separate the left and right side protectors as stated in Sect. A.3.1c of the EXP-08-17 document. Only the right side protector was tested in this instance.

Preparation and positioning of samples

All hip protectors were inspected for any manufacturing defects prior to testing. Each hip protector sample was then ink-marked on the outer surface to indicate the position of the greater trochanter (when the hip protector is worn in accordance with the manufacturer's instructions). In cases where the desired position of the greater trochanter was not specified by the manufacturer, the geometrical centre of the impact protector was positioned over the greater trochanter. Double-sided tape was used to secure each hip shield over the silicone soft tissue simulant covering the aluminium femur form (Fig. 2f). The hip protector was positioned directly over the centre point of the greater trochanter. Samples were also tested for "out of position" alignment at 50 mm displacements in the anterior, posterior, and lateral positions, to assess the efficacy of the hip shield if misplaced from the manufacturer's intended position.

Mechanical testing

The drop-weight assembly was vertically released from a height of 0.5 m to ensure an impact velocity of 3.2 m/s was achieved. The force during impact was displayed on the oscilloscope and recorded as a CSV file, which could later be processed in Matlab (Mathworks, R2018). The sample was then removed and inspected for visible signs of external damage before repeated tests were performed. Each hip protector was tested five times in the centre position and once in each of the misplaced positions. Two sets of tests were conducted in this study. The first test (test I) measured the maximum peak force and percentage reduction in the centre position only, i.e. the hip protector was positioned directly over the greater trochanter. The second set of tests (test II) included the maximum peak force and percentage reduction in the centre, anterior, posterior, and lateral positions. Two additional hip protectors, Delloch Plus and Pelican Green, were added to the second round of tests. Noting, with the exception of Delloch Plus and Pelican Green, the same hip protectors were used for test I and test II.

All testing was performed by the same observer (Dr Bethany Keenan). Each hip protector was tested once to ensure a minimum of 2 min elapsed before repeated impacts were conducted. Positions were changed systematically, i.e. all hip protectors were tested 5× in the centre position, once in the anterior position, and once in the posterior position followed by once in the lateral positions (right then left side).

Data analysis

All tests were recorded with a sampling frequency of 10 kHz. A low-pass fourth-order Butterworth filter with a cutoff frequency of 37 Hz was applied to the data (during post-processing) to produce a smooth force-time curve. The maximum value of force on this processed data (in N) is used as the measure of the peak force. An example of the force-time graphs produced in Matlab is shown in Fig. 4, where the solid blue line represents the raw data and the orange dashed line is the filtered data.

Results

Considerable differences were identified between individual hip protectors in their ability to reduce impact forces on the femur. A peak force reduction of up to 36% can be achieved if a hip protector is worn in the intended position whilst falling. The mean maximum peak force attenuation and standard deviation in the centre position was 13.59 (SD 7.96) % in test I compared with 16.91 (SD 6.78) % in test II.

For the additional out of position measurements in test II, the mean maximum peak force and standard deviation was 10.89 (5.93) %. The percentage in peak force reduction in the centre position ranged from 6% to 28% for test I, increasing from 3% to 36% for test II (Table 1). The average thickness of the hip protectors was 15.5 mm (range 6–25 mm).

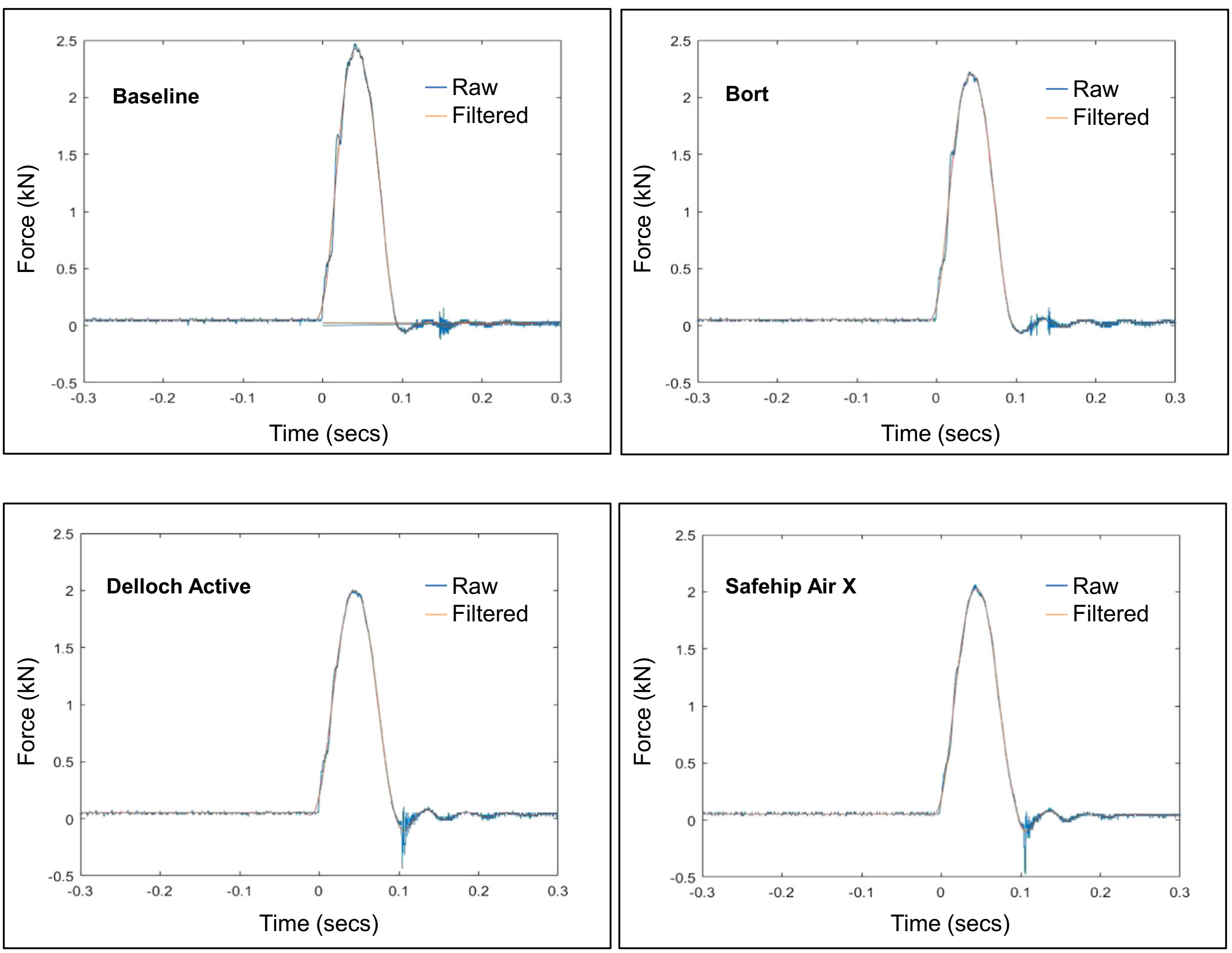

Fig. 4 Examples of force-time graphs produced in Matlab. Where raw data is shown in blue and filtered data using a low-pass fourth-order Butterworth filter is shown in orange

Table 1 Shell type, pad thickness and mean attenuation in peak force (standard deviation) for Test I and Test II, where each hip protector was tested five times in the centre position over the greater trochanter

Sample #	Shell type	Pad thickness (mm)	Mean attenuation in peak force test II with standard deviation (%)	Mean attenuation in peak force test I with standard deviation (%)	Overall rank
Baseline	–	0.0	0.00	0.00	-
Suprima	Soft	14.5	2.63 (SD 1.47)	5.86 (SD 2.47)	18
Bort	Soft	12.0	3.46 (SD 0.65)	6.58 (SD 3.14)	17
Impactwear Active	Soft	15.0	4.86 (SD 0.54)	10.10 (SD 2.86)	16
Fallsafe	Soft	13.0	7.15 (SD 0.91)	11.96 (SD 3.58)	15
Hornsby Comfy Hips	Soft	18.0	8.62 (SD 1.33)	18.13 (SD 2.03)	14
Cubro Softech	Soft	6.0	9.27 (SD 0.66)	14.62 (SD 0.42)	13
Delloch Slimline	Soft	10.0	10.16 (SD 0.31)	14.66 (SD 4.38)	12
Hipshield	Soft	14.5	10.85 (SD 1.01)	16.70 (SD 3.96)	11
Pelican Green	Soft	19.0	10.93 (SD 2.58)	–	10
Pelican Super Soft	Soft	25.0	12.30 (SD 1.34)	12.63 (SD 3.13)	9
Safehip Air X	Soft	18.0	14.18 (SD 3.55)	19.48 (SD 2.53)	8
Delloch Active	Hard	18.0	15.95 (SD 0.78)	21.41 (SD 2.82)	7
Delloch Closed	Soft	14.0	17.78 (SD 0.92)	23.34 (SD 3.31)	6
Hipsaver	Soft	17.0	18.07 (SD 0.60)	20.26 (SD 3.14)	5
Hips	Hard	16.0	18.12 (SD 1.53)	22.66 (SD 3.73)	4
Delloch Flexi	Soft	20.0	19.33 (SD 1.62)	23.92 (SD 3.11)	3
Delloch Maxi	Soft	20.0	23.47 (SD 0.58)	27.63 (SD 2.64)	2
Delloch Plus	Hard	9.0	36.20 (SD 0.95)	–	1
Overall average (SD)	–	15.5	16.91 (SD 6.78)	13.59 (SD 7.96)	-

When the pad was misplaced at 50 mm displacements in the anterior, posterior, and lateral positions, the effectiveness of the hip protector reduced by up to 17%. The results for the average attenuation in peak force reduction when the hip protector is misplaced from its intended position are shown in Fig. 5. Twelve out of the 18 hip protectors attenuate the force by 10% in the centre position, but only two out of the 18 protectors attenuate the force by 20%. Thirteen out of the 18 hip protectors performed the worst when the pad was displaced 50 mm in the anterior position.

Discussion

The aims of this study were (a) to compare the force attenuation of all hip protectors tested and (b) investigate the effect of pad positioning if misplaced from the intended position in accordance with the methods and values given in the CSA EXP-08-17 document.

This study has shown that the range in force attenuation among all hip protectors varies considerably in the manufacturer's intended position. Some protectors perform well, but others are almost ineffective, providing little to no protection to the wearer during a fall. These hip protectors should be avoided. The position of the hip protector influenced the forces applied to the femur and consequently was seen to significantly impair the efficacy of all hip protectors. Both the hard and soft shell types performed well and badly; therefore, it is not possible or appropriate to draw general conclusions about which is best.

Whilst there is currently no "threshold" for force attenuation, it is interesting to note that the Hips, Delloch Flexi, Delloch Maxi, and Delloch Plus consistently provide a force reduction of ≥ 15% in both intended and misplaced positions. Looking at the characteristics of each of these products, it is clear to see that the shape, surface area, and thickness potentially play an important role in attenuating this force. Both the soft-shell Delloch Maxi and Delloch Flexi protectors have a thickness of 20 mm, but the Maxi has a larger surface area and is rectangular in shape, perhaps accounting for the 4% attenuation difference between the two products. Surprisingly, when we look at the two hard-shell protectors, the Delloch Plus oval-sized protector is 7 mm thinner than the Hips round shaped protector (16 mm); yet, the difference in attenuating the force is significantly higher, 36% to 18%, respectively.

Whilst it is difficult to determine whether a trend exists between force attenuation and the thickness of the hip protector, it is important for manufacturers to consider the design parameters of the hip protector. A pad too thick or too hard is going to be uncomfortable for the user and may not be worn;

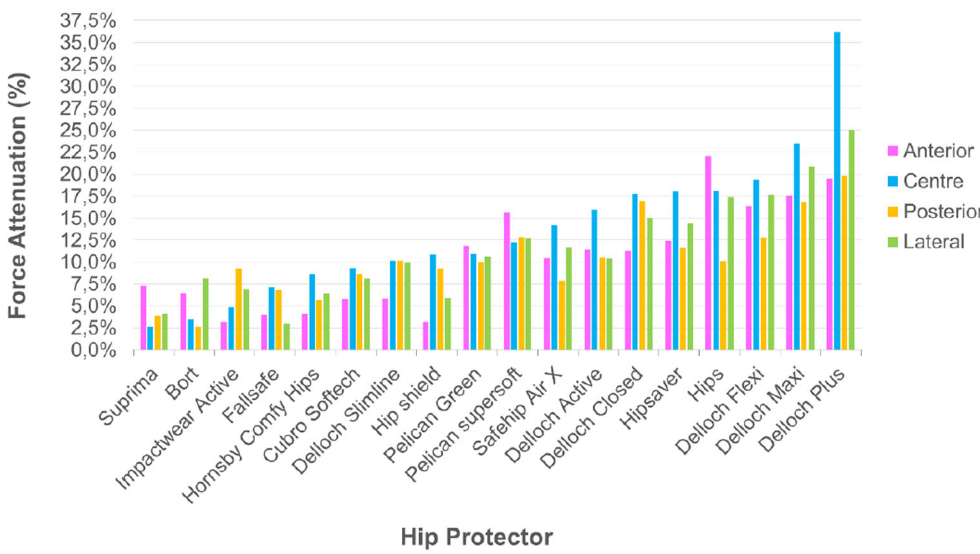

Fig. 5 Photograph showing each hip protector (above) with corresponding peak force attenuation results for the anterior, centre, posterior and lateral positions

yet, a pad that is too thin may not provide sufficient protection. We found no significant correlation between thickness and impact force reduction (Pearson's correlation coefficient, $r = 0.27$ for test I and $r = 0.05$ for test II). There is a practical minimum thickness that is needed because some distance is required for the body to decelerate as the pad is compressed; in our tests, no soft protector less than 13-mm thick achieved more than 14.66% force reduction. One hard shell design achieved a high force reduction (Delloch Plus, 36.2%), although it was only 9 mm thick, but this is because it stands away from the body at the trochanter; so, its effective thickness is much greater, and the hard material may cause other comfort issues. Our sample of 18 hip protectors reflects the range of hip protectors commercially sold in Australasia and Europe in 2018. With more manufacturers focusing on soft-shell hip protectors, we were only able to source three hard-shell protectors for this study. This is reflective of the current market where the hard-shell type protectors have slowly been phased out and replaced by soft-shell protectors for increased comfort and user compliance.

Whether the hip protector is to be replaced by a new device after a single impact or reused depends on the manufacturer. However, even when the manufacturer specifies that the device should be replaced, this may not always happen in practice, and so, performance under repeated impacts is of interest. In this present study, we wanted to assess the efficacy of the protector with repeated impacts to see how (or if) the protector was impaired in any way. In fact, when the protectors were tested repeatedly, no degradation in their performance was observed, even following repeated impacts in the same position. In some cases, there were some minor marks and cosmetic damage, but this did not appear to impair their performance.

The wide range in biomechanical performance observed in this study is in keeping with existing literature. Laing et al. reported a force attenuation range from 2.5% to 40% with an impact velocity of 3 m/s [20]. This compares favourably with our study of 3% to 36% at an impact velocity of 3.2 m/s. Our results for the Hipsaver protector (a commonly sold and tested hip protector) also compared favourably with two studies by Laing et al., whereby our study reports 20.26% (test I) and 18.07% (test II) compared with 20.9% and 23.5% by Laing et al. [20, 21]. Other studies which tested the Hipsaver protector, for example, Choi et al. (2010) and van Schoor et al. (2006), report much greater force attenuation of 45% and 45.6–57.8% [17–19]. The impact velocities used in these studies were lower at 1.98 m/s and 1.25 m/s, respectively. Furthermore, van Schoor et al. simulate a severe fall, which causes larger peak force. This further highlights the importance of comparing hip protectors, which use the same test design parameters.

It is interesting to note the overall ranking of common hip protectors tested in both the present study and by Laing et al. The hip protectors ranked similarly between the two studies, indicating that some protectors perform consistently well and others are consistently poor at attenuating the peak force. The Hipsaver protector ranked 5th for this study and 7th by Laing et al., Bort 17th and 23rd, Safehip Air X 8th and 5th, Pelican super soft 9th and 4th, Hornsby Comfy Hips 14th and 18th, and Hipshield 11th and 20th, respectively [20].

It is an acknowledged limitation of this test method that the results can vary slightly on repeated testing. In this study, we found moderately consistent results within a single testing session (standard deviation $< 4.5\%$), but larger differences when the same set of protectors were retested on a subsequent occasion. The peak forces were not significantly different ($p \leq 0.01$) between the two sets of tests. This gives some confidence in the repeatability of the method, but further work is still needed to evaluate repeatability and reliability in a multi-centre study.

Since there are a large number of products with similar performance, these variations can lead to minor changes in the ranking. However, it is clear that there is a group including Bort and Suprima that perform consistently badly in both correct alignment and out of position. The Delloch products were consistently among the best of all the protectors that were tested. Moving the protectors out of position led to significant reductions in performance in many cases, but all of them still offered protection regardless of the exact position. This is important since it is difficult or impossible to position a protector very accurately when it is worn by a user. The position depends on a body shape, garment design and fit, and user knowledge and lifestyle.

The peak force measured during the unpadded condition (a mean of 2.3 kN for test I and 2.41 kN for test II) is lower than the 2.5–3.0 kN range included in the CSA document. This could be due to the thickness and material of our soft tissue simulant.

The method presented in the express document has been based on extensive research, notably by Robinovitch et al. [27, 30], including a series of tests on human subjects, and the impact velocity, mass, and spring stiffness are based on these tests in order to accurately simulate a real fall. This is in contrast to other tests, such as the EN1621 motorcycle hip protector test [31], which uses an unrealistic mass and stiffness, resulting in very high impact forces that exceed the strength of the femur by an order of magnitude even when using a protector. There is a danger that such unrealistic tests may influence the design of protectors, which may be optimised to perform well in the test at the expense of performance in a real fall. This is particularly important with the increased number of older adults gaining a motorcycle licence (50% of adults over 50 with licences are women [32]). With the known prevalence of osteoporosis among older women, we should not rule out the need for a hip protector, which caters for those living a more active lifestyle.

We acknowledge that a hip protector tested to be biomechanically effective in a laboratory setting does not necessarily mean that it would be clinically effective. However, given the time and cost involved in conducting a large clinical trial in a hospital or care setting, we would recommend initially conducting mechanical testing to eliminate those hip protectors, which are largely ineffective at reducing the peak force in both correct alignment and out of position.

This is the first study that uses a standard mechanical test on hip protectors. Previous studies have involved a variety of testing methodologies, a factor that often renders it difficult to interpret results. The study demonstrates that the CSA document can be used to test and compare hip protectors and is potentially a valuable tool for evaluating hip protectors that could provide useful data for clinicians, users, and purchasers. Future work will involve multi-site testing of the same protectors and further verification of the repeatability and reliability of the method.

Compliance with ethical standards

Conflicts of interest Sam Evans was a consultant to the Ascent Group on hip protector design and testing and Dow Corning on impact protection materials and testing. Both Sam Evans and Bethany Keenan are consultants for Delloch and SpineCor. Delloch provided the majority of the hip protectors for this study.

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