

Technical Report

**FORCE ATTENUATION CHARACTERISTICS OF DIFFERENT FORCE  
ABSORBING MATERIALS USED IN A HIP PROTECTOR FOR THE ELDERLY**

December, 2005

by

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**This is an abstract of an extensive study where the overall goal of the project was to investigate the amount of impact force attenuated by different combinations of foam and polypropylene materials. It was anticipated that the results would provide experimental data to the Sponsor in determining the optimal materials to be used in a hip protector distributed by the Sponsor.**

## **FORCE ATTENUATION CHARACTERISTICS OF DIFFERENT FORCE ABSORBING MATERIALS USED IN A HIP PROTECTOR FOR THE ELDERLY**

Falls among the elderly can be traumatic and potentially life threatening (13, 21). Injuries sustained at the hip during a fall can range from minor bruising to more catastrophic fractures of the femur. As a result, the risks of morbidity, disability, long-term institutionalization and death all increase (2, 6, 8, 18). The occurrence of fractures is associated with a direct impact to the trochanteric area of the hip (4, 11), and the severity of the injury is affected by the falling mechanisms, the impact energy during the fall, and the energy absorption of the soft tissue in the surrounding area (4). One method of preventing or diminishing the severity of injuries during falls is to protect the hip with external padding.

Previous research suggests that hip padding or hip protectors are a viable method of preventing hip fractures. Research suggests that hip protectors may help reduce the incidence of hip fractures by more than 50% (5, 7, 9). However, when evaluating the force attenuating characteristics of such padding, it is important that testing conditions simulate realistic impact conditions. Hip protectors should be evaluated in terms of impact energy, effective mass, stiffness, and damping of the body during impact (16). Ideally, when tested under realistic conditions, an effective hip protector should lower impact forces delivered below a critical level required to cause injury.

In order to evaluate the ability of a hip protector to attenuate impact forces below some threshold value, the amount of impact force sustained during a typical fall without protection must be determined. According to an investigation by Robinovitch et al. (15), impact forces to the proximal femur during lateral, standing falls can range between 5,000-8,000 N. However, Wiener et al. (21) reported impact forces to the proximal femur ranging between 7,031 - 26,517 N when using human subjects. Therefore, depending on the hip model and falling mechanism (orientation of the greater trochanter at the time of impact) used, impact forces to the hip during a fall can range between 5,000 to 26,517 N.

Impact forces sustained during a fall are applied to the lateral aspect of the hip, and are attenuated by surrounding soft tissue before reaching the greater trochanter of the femur. Research suggests that the various surrounding soft tissues in the human body (skin, adipose, muscle tendons and surrounding bony structures) may all contribute to the attenuation of impact forces (1, 12, 19). According to an investigation by Robinovitch et al. (17), trochanteric soft tissue attenuated peak femoral impact by an average of  $13 \pm 15\%$ , and increased linearly with increasing thickness (approximately 70 N per 1 mm change in thickness). Therefore, external force sustained at the hip during a fall will first be attenuated by soft tissue in the surrounding area.

Although the soft tissue may be injured through this attenuation process, the amount of force transmitted through the soft tissue is of greater concern because it may still be large enough to cause injury to the underlying bony structures. Several studies have simulated the hip complex and forces sustained during a fall in order to determine the threshold or critical force value necessary for a fracture of the femur to occur. Depending on the loading rate used, reported loads necessary for hip fractures have varied. When loading simulated hip complexes, fast deformation rates required 4,170-6,020 N for fracture, medium deformation rates required 3,510 N for fracture, and slow deformation rates required 1,030-2,110 N for fracture (3, 10, 20). Of these values, the most common threshold values used for comparison in the literature are  $4,113 \pm 1,527$  (10) and  $4,170 \pm 1,590$  N (3).

All testing was conducted in the Biomechanics Laboratory located in the Center for Exercise Science at the University of Florida. Components were supplied by several manufacturers and were evaluated using an impactor apparatus. The apparatus consisted of an impactor, custom made at the University of Florida that was located directly above a forceplate (Model 4060, Bertec Corporation, Columbus, OH). A metal plate (12 mm thick) was secured on the forceplate to prevent damage to the top plate of the forceplate. Data were collected using EvaRT software (Motion Analysis Corp., Santa Rosa, CA) and sampled at 10,000 Hz.

The amount of impact force being delivered in the experiment was manipulated by using different drop masses and drop heights. As a result, there was a total of nine impact conditions (3 masses x 3 heights).

### Session I

Baseline Impact Tests were completed on June 7th, 2005, to determine the amount of force being attenuated by the use of a padding, the force transmitted without the use of a padding (the so-called baseline value) must be known. Therefore, baseline impact forces were collected without placing any force absorbing materials between the striker and forceplate. The striker (3.18 kg) was dropped from several drop heights, starting at 0.05 m and increasing in increments of 0.05 m, until peak forces values reached a magnitude large enough to potentially damage the forceplate (i.e., exceeding the rated load of 18,000 N of the forceplate). The baseline tests reached a maximal drop height of 0.4 m for the flat striker and 0.35 m for the round striker.

Honeycomb Testing: The hip protector under investigation is intended to be comprised of three layers – an outer foam layer, a middle honeycomb layer with the primary function of force attenuation, and an inner foam layer for user comfort. To get a better idea of the type and thickness of honeycomb to be tested in Session II, impact tests were performed on seven different honeycomb boards supplied by a potential supplier of the Sponsor. Using the impactor apparatus, each honeycomb board was impacted with the flat striker under nine different impact conditions. As a result, a total of 54 impact tests were completed (6 boards x 9 conditions). For each impact test, the peak force transmitted through the honeycomb was identified from vertical ground reaction forces recorded by the forceplate and the amount of material deformation (indentation depth) was measured using a caliper.

### Session II

Testing was completed on June 18, 2005. The primary purpose of this session was to perform impact tests on different combinations of foam as inner and outer layers and honeycomb as the middle layers. The Sponsor provided a large number of thick foam boards of different colors for the outer and layers:

- \* Gray (G) – high density and less flexibility
  - \* Blue (B) – medium density and medium flexibility
  - \* White (W) – low density and more flexibility
- (These colors are not correlated to the final color of the hip protectors)

Honeycomb boards from two different suppliers were used. Boards from these two suppliers were labeled as H1 and H2. Therefore, 18 different foam-honeycomb-foam (FHF) combinations (3 inner layers x 2 honeycombs x 3 inner layers) were available for testing. These 18 FHF combinations are also called *padding combinations* in this report.

To simulate the shape of the greater trochanter of femur, a round striker head was also used in addition to the flat head. As a result, a total of 18 impact conditions (3 drop masses x 3 drop heights x 2 heads) were applied to each padding combination. In other words, a total of 324 tests (18 impact conditions x 18 padding combinations) were planned for this session. During each impact test the impact forces transmitted through the padding were recorded by the forceplate underneath the padding. In each trial, the layers of padding were tightly fitted inside a wooden frame and placed under the striker of the impactor apparatus. Impact tests were conducted sequentially in order from the least amount of impact energy to the greatest amount of impact energy. For each padding, peak impact forces were identified immediately after trials of medium and high impact energies. In the event that the peak impact force recorded for a particular padding for a given impact energy level reached a magnitude close to the maximum rated load of the forceplate (18 kN), impact tests of higher impact energies were not performed for that padding to prevent damage to the forceplate.

Session III - This third testing session, completed on July 29, 2005, was added in order to determine the force attenuation properties of a honeycomb board similar to H1 but slight thinner than the H1 used in Session II (labeled as H1b). Because only Gray-H1b-Gray (G-H1b-G) and Blue-H1b-Gray (B-H1b-G) combination were chosen for testing, a total of 36 tests (18 impact conditions x 2 FHF combinations) were planned for this session. For each combination the testing protocol was the same as in Session II. Since certain impact conditions of high impact energies were not conducted to prevent damage to the forceplate, the total number of tests completed was less than originally planned.

## **CONCLUSION**

The impact forces delivered with the lowest drop mass (3.18 kg) and lowest drop height (0.4 m) during the current investigations were believed to approximate realistic impact forces sustained during standing lateral falls. The material tested in the current investigation attenuated between 57.1 and 87.2 % of the peak force delivered. In addition, many of the padding combinations reduced the peak impact force to values below a critical level known to cause hip fractures in elderly. Among different impact conditions, the FHF combinations using 7mm gray foam pads as inner and outer layers consistently performed better than the other combinations in terms of peak impact force attenuation. Therefore, it is anticipated that a hip protector made with a G-H-G combination will be the most effective in preventing hip fractures during a fall.

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