BIOMECHANICAL EFFECTS OF SHEER THICKENING POLYMER (STP)-BASED HIP PROTECTORS

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External hip protectors are used by the elderly in preventing hip fracture due to sideway falls. There are some commercial hip protectors which has both energy absorbing and energy shunting properties. In this study, a novel hip protector using shear thickening polymer (STP) is studied. The purpose of this work is to determine the optimal thickness of STP needed for maximum force attenuation. A mechanical test rig to simulate a person falling with sufficient impact energy to fracture the greater trochanter if unprotected was used together with biofidelic femur model which simulates the layer of flesh with skin. 8mm of STP together with 5mm foam gives the best force attenuation. When comparing the overall thickness with commercial hip protectors, STP hip protectors tested have much less thickness. Reduced thickness increases the compliance and comfort of STP hip protectors.

KEYWORDS: HIP PROTECTOR, HIP FRACTURE, IMPACT TEST, SHEAR-THICKENING POLYMER (STP)

INTRODUCTION: Wearing hip protectors is a preventive measure to ensure that a fall does not lead to hip fracture among the elderly by reducing the impact of the fall(Kannus et al., 1999). According to a study conducted by Sawka et at.(Sawka et al., 2007), hip protectors are proven to be effective in decreasing the risk of hip fracture in elderly nursing home residents.

Shear-Thickening Polymer (STP) has unique rheological properties, where its viscosity increases with the increase in shear strain in time dependent manner(Ballard, Buscall, & Waite, 1988; Robinovitch et al., 2009). STP is already in use for some commercial products like the Kevlar fabrics for body armors, human protection gears and drilling fluids in the oil industry(Neagu, Bourban, & Månson, 2009).

In this study, we intend to use the STP's unique properties for hip protectors to increase the force attenuation capacity of hip protectors and also to decrease the overall thickness of the hip protector. To test our hypothesis, we used a drop weight impact testing system mounted with an anatomical hip model and an embedded tri-axial load cell in the femoral neck of the hip model. STP hip protectors of different thickness were prepared and two sets of mechanical testing at low and moderate impact energy were conducted for each hip protector.

METHODS: The anatomical hip model was designed based on a digital 3D model constructed using the CT scans of 10 subjects and a hip model schematic proposed by Derler et al.(Derler, Spierings, & Schmitt, 2005). The geometry of the hip model was first proposed by Viceconti et al. in their study to standardize the femur model for research purposes using finite element analysis(Viceconti et al., 1996). A tri-axial Kistler Type 9047B load cell was embedded in the femoral neck region between the femur bone and the screw-on femur head.

The femur was also orientated by an angle of 10º to the horizontal plane to mimic the single-leg stance mode. A study by Robinovitch et al. (Robinovitch, McMahon, & Hayes, 1995) established the importance of the effect of soft tissue around the greater trochanter in absorbing some of the impact energy from a sideway fall. Thus, a flesh surrogate made of soft flexible foam with a thickness of 3 cm was mounted on the femur model.

Stainless steel was chosen as the material for the femur model as it has high tensile strength and corrosion resistance. As the model will undergo multiple and repeated impact loading of up to 10 kN, the material chosen has to be able to withstand such high loading. Figure 1A shows the Stainless steel model without flesh surrogate. The load sensor is also made of stainless steel and was chosen for its high measuring range, rigidity and durability against high impact multiple loading. The load sensor is placed at the femoral neck region as shown in Figure 1B. This will allow us to measure the force reaching the femoral neck for each fall.

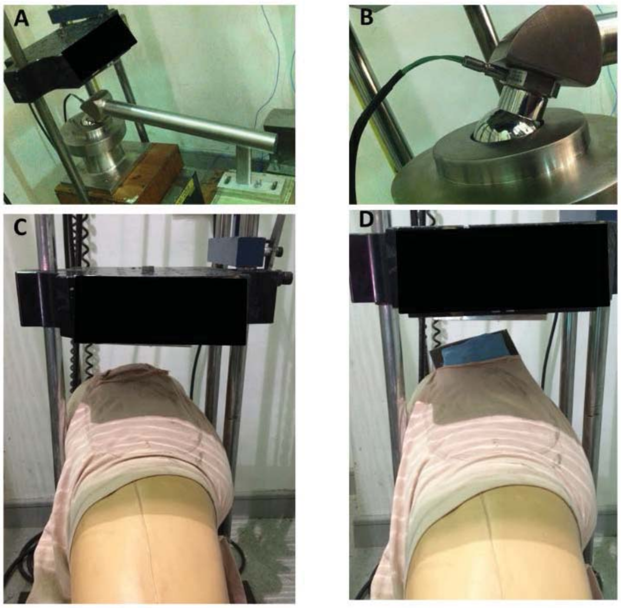

Figure 1: A – Anatomical hip model. B - Close up view of force sensor location. C – Hip model with flesh and underwear with pocket. D – Foam and STP inside the pocket.

Drop weight impact system was used for the mechanical testing. The machine used consisted of a 13 kg weight mounted onto two guides which were frictionless and the weights were dropped in free fall from a predefined height. The rectangular weight block had a flat surface to emulate the flooring which was assumed to be flat.Two series of biomechanical experiments were carried out - low impact energy and moderate impact energy. Each hip protector was subjected to 3 trials for each series of experiments.
The new hip protector was developed based on the properties of shear-thickening polymer (STP). We prepared STP of 5 different thicknesses. When testing STP 5mm foam was placed in between the flesh surrogate and STP. The STP and foam were placed into underwear with pockets by the side with foam material being in contact with the flesh side and STP on the outside as shown in Figure 1C and 1D. Table 1 shows the thickness and material compositions of the 7 samples that were tested.

Table 1: Thickness and composition details of the hip protector samples made

Hip Protector	Thickness of Foam(mm)	Thickness of STP(mm)
1	5	0
2	10	0
3	5	4
4	5	6
5	5	8
6	5	10
7	5	12

RESULTS AND DISCUSSION: Figure 2 shows the compilation of all the resultant peak forces (average of 3 impact test) when tested without hip protector (reference) and with the 7 hip protector samples.
At 25J of impact energy, sample with 5mm foam only gave resultant force of 2.17kN while 10mm foam only gave 1.98kN. When STP of 4mm thickness was used together with 5mm foam, the resultant force was 1.72kN. As the thickness of STP increases the resultant force decreases. However, the decrease in resultant force gradually plateaus off as the thickness of STP increases beyond 8mm. With 8mm STP and 5mm foam, the force attenuation capacity is 34.9%. When the thickness of STP is increased to 10mm, the force attenuation capacity is only 32.3% while 12mm STP has force attenuation capacity of 32.8%.
At 44J of impact energy, sample with 5mm foam only gave resultant force of 4.97kN while 10mm foam only gave 4.86kN. When STP of 4mm thickness was used together with 5mm foam, the resultant force was 4.27kN with force attenuation of 16.4%. Similar to impact testing at 25J the resultant force decreases as the thickness increases and plateaus off when the thickness increases beyond 8mm. With 8mm STP and 5mm foam, the force attenuation capacity is 22.1%. When the thickness of STP is increased, the force attenuation capacity is 23.1% and 24.1% at 10 and 12mm thickness respectively.

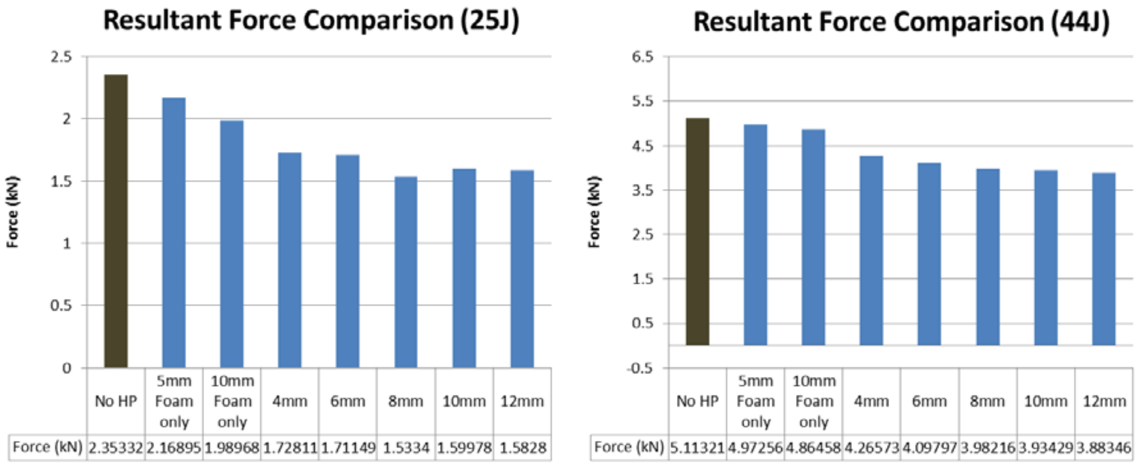

Figure 2: Peak resultant force measured without hip protector, with 5mm foam only, with 10mm foam only,4mm STP, 6mm STP, 8mm STP, 10mm STP and 12mm STP for impacting testing at 25J and 44J.

The aim of this study is to identify the optimal thickness of STP needed to provide the maximum force attenuation without increasing the overall thickness beyond 17mm. 17mm is chosen as the limit as most commercial hip protectors in market have an average thickness of 15-17mm for soft-shell hip protectors and 12-16mm for hard-shell hip protectors. Biofidelic femur model as well as the drop weight testing system used in this study was adapted from the previous studies to ensure our results are in line with the international standards.
STP hip protectors are backed with foam material at the side in contact with the flesh. As STP stiffens upon impact, instead of shunting the force away from the greater trochanter, it might transmit the force directly to the flesh above the greater trochanter region. To avoid this undesirable effect, a foam layer is added to give a soft surface for STP to be in contact with and hence reducing force from being directly transmitted to the flesh above the greater trochanter. Foam layer also gives some time delay for STP to spread the force over a larger area of flesh.
It can be seen from the experiment that using 5mm or 10mm foam alone does not reduce the impact force significantly. Hence, when STP is used together with 5mm foam, the resulting force attenuation is due to STP. STP thickness beyond 8mm does not reduce the impact

force significantly. The resultant force tends to plateau off when the STP thickness is increased from 8mm. This could be due to the properties of STP, as when the thickness increases, STP becomes heavier and its hardness upon impact also increases drastically. Hence, when the STP hip protector becomes very hard, it is unable to absorb or divert the impact force. Instead it transmits all the impact force directly to the flesh. This can be the reason as to why the increase in thickness of STP does not result in significant decrease in resultant force measured.

Using 6mm or 8mm STP together with 5mm foam backing is optimal for maximum force attenuation without increasing the overall thickness over 17mm. Though using 8mm STP gives a better result, STP itself can get heavy. This will be uncomfortable to the wearer. Hence, we recommend choosing either 6mm or 8mm STP according to the individual's physical need. 8mm STP hip protectors can be used for someone with higher BMI while 6mm can be used for those with lower BMI.

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