Hip Protectors: Comparative Study of FEM Simulation and Testing

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Abstract

The hip fracture is a serious problem especially for elderly. However, it can be prevented by using a hip protector. The purpose of this work was to compare the impact force reduction of four different cases of a bare femur (A), a femur covered with a soft tissue (B), and a femur covered with the tissue and a hip protector type I (C) and type II (D). The results were analyzed with the FEM. The impact test was performed by dropping a weight of 4.75 kilograms from a height of 52 cm on to a pelvis. The measured impact force was measured and readout directly from a load cell. It was found that the measured impact forces from A, B, C and D systems were 7,797, 5,561, 1,546 and 1,177 N, respectively. It can be compared with the force analyzed from the FEM of 7,535, 5,228, 1,927 and 1,424 N, respectively. Both results differ in a range of 200-400 N. Thus, the FEM was assured to use as a tool for a successful design of a high-perform hip protector.

Keywords*:* Hip, Hip fracture, Hip protector, femur, bone.

1. Introduction

Hip fracture is a serious problem especially for elderly women due to the broken of a weak femur bone. There are more than 90% of hip fracture cases resulted from a standing fall [1,2] which 33% found for elderly women and 17% for elderly men [3]. In Chiang Mai, Thailand, in 1998, everyone in 550 people was found having a hip fracture each year due to the community survey [4]. Hip fracture is the important causes of morbidity and mortality of the elderly in the severe cases. After fracturing of a hip, life expectancy was shortened by approximately 6 years of both men and women [5]. The estimated cost of hip fracture treatment was 120,000 baths in the first year [6]. Prevention of a hip fracture was not only for earning good health but also reducing cost of the treatment.

There are many risk factors of hip fracture including age, osteoporosis and force applying to the hip. However, two important risk factors of force and hip strength were reported from the previous study [7].

Hence, to prevent hip fracture, there are two successful methods; 1) reducing of the force acting to the hip by covering it with a special tissue such as hip protector and by using modified floor, and 2) increasing bone mass and hip strength by using medication but it might have a side effect of allergy. From the report of the Japanese nursing-home residents, it was only one out of 131 falls found having the fracture for whom wearing a hip protector. In contrast, eight out of 90 were found having the fracture for whom without wearing a hip protector [8].

The finite element method (FEM) helps to reduce the tremendous testing works of different models of the sample to acquire the final model of the product. Hence, the purpose of this study is to verify the simulation results from the FEM with the testing results to compare the two different models of hip protectors.

2. Material and methods

2.1 Material of hip protector

In this study, two models of a hip protector were made of different layers of polypropylene (PP) and natural rubber (NR). The outmost layer was made of a curved PP shell while the inner layer was made of NR foam. The PP shell was expected to absorb most of the force and the soft foam was expected to absorb the rest prior to transferring to the bone. In addition, this foam makes a better feel of contact. Both type I and type II models of hip protectors shown in Fig.1I and Fig 1II, respectively.

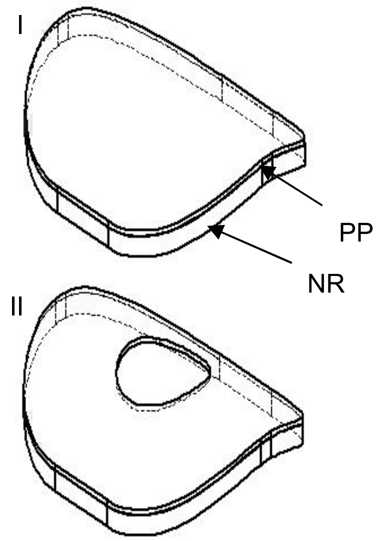

Fig.1 Hip protectors (Type-I (upper) and Type-II (lower))

2.2 Biomechanical testing and equipment

The impact testing was conducted by dropping a 4.75 kg steel mass from a height of 52 cm onto the femur. This set similar to the sideway fall simulation. This test earned an impact velocity of 3.01 m/s comparable to the velocity of the fall initiated from walking and/or standing [9]. The maximum impact force of about 7,591 N was generated which was comparable to the impact force from falling without soft tissue of the previous studies [10,11].

Silicone material was chosen to simulate as a human tissue due to their similarities. Within a thickness range of 14-16 mm, it could reduce the impact force about 29% compared to about 15-20% reduction of the human tissue at a thickness range of 18-20 mm for elderly women whom had hip fracture [11,12,13]. This testing consists of 4 different models shown in table 1.

Table 1 Testing Models

Model	The soft tissue	Type of hip protector
A	-	-
B	✓	-
C	✓	I
D	✓	II

The test was started with model A to determine the maximum impact force on the bare femur. The test of model B was carried on to determine the effect of soft tissue on the reduction of the impact force. Model C and D were tested to investigate the reduction of the force due to the present of different hip protectors of type-I and type-II, respectively. For all tests, the viscoelastic response (force vs. time) was investigated and the peak force was reported.

Four main parts of the testing apparatus were shown in Fig.2 and it consists of a metal frame, a femur model made of aluminum, a steel drop weight and a load cell. The load cell chosen was piezoelectric type (Kistler 9321B) equipped with amplifier (Kistler 5093A) and data acquisition system (DAQ NI 6009).

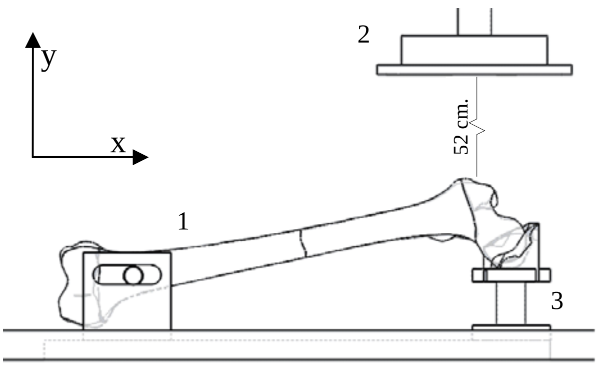

Fig.2 Assemble of testing apparatus (1: an aluminum femur, 2: a 4.75 kg steel mass and 3: a load cell)

For accepting benchmark, a hip protector can protect hip from fracture if it can reduce the maximum force to a lower than 3,100 N. This reference value was acquired from the threshold average force before fracture of the hip bone of the elderly [14,15].

2.3 Numerical simulations

Numerical simulations of various models were archived by using the finite element program (MSC-Marc 2007) with a tetrahedron element type (Marc element tet4). In these simulations, the steel weight was dropped onto the models and the peak forces of impact were measured. Each testing model for FEM was shown in Fig.3. Details of material properties of simulation were shown in table 2, the Boundary condition for the transient dynamic FEA was shown in table 3 and the results of materials (silicon and natural rubber) behavior were shown in Fig. 4 and Fig. 5, respectively.

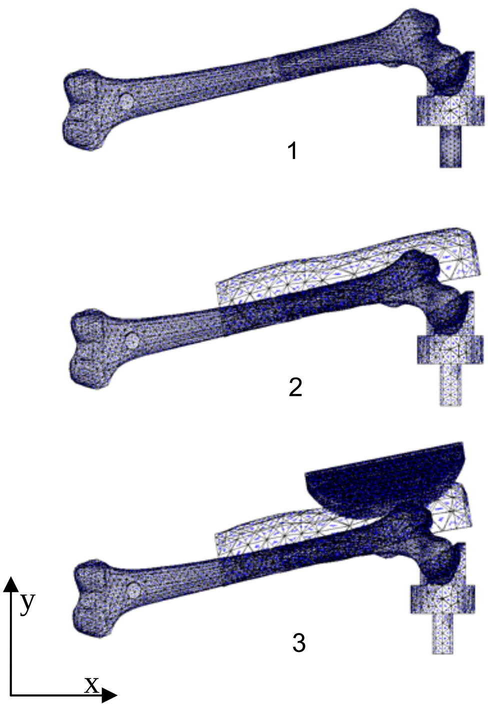

Fig.3 Testing models (model A (1), model B (2) model C&D (3))

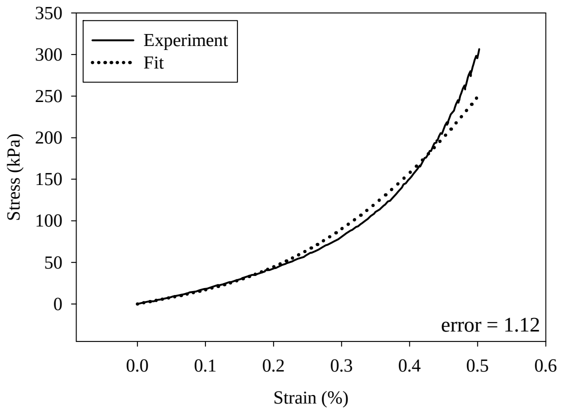

Fig.4 Silicone property

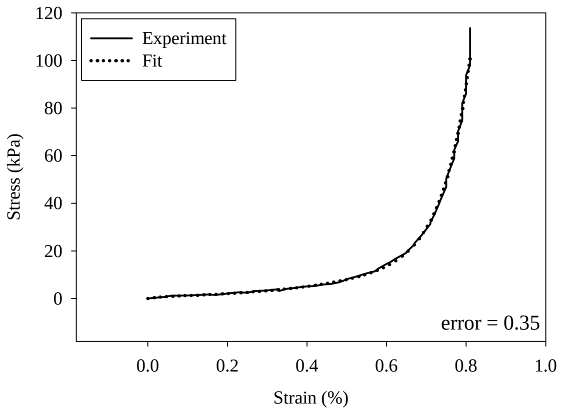

Fig.5 Natural rubber property

Table 2 Material properties

Materials	Modulus (GPa)	Poisson ratio	Density (kg/m^3)
Steel	200.0	0.29	7,900
AL-356	72.4	0.33	2,670
Polypropylene	3.0	0.35	1,190
Natural rubber	-	-	144
Silicone (soft tissue)	-	-	903

Table 3 Boundary condition for the transient dynamic FE analysis

Body	Type of BC dynamic
Steel impact or striker	Mass 4.75 kg Gravity 9.81 m/s^2 Height 0.52 m Fix displacement xz
Bolt	Fix displacement yz
Load cell	Fix displacement xyz

3. Results and discussion

From testing, the maximum value of the impact force acting on a bare femur was found at 7,797 N. It was compared with the value of the FEM simulation at 7,535 N. The difference was about 262 N. Both values were agreed with the maximum value of 7,800 N set by the previous study [10,11].

After covering the soft tissue on the femur bone (model B), the impact force was reduced to 5,561 N and it was different from the simulated value at 5,228 N about 333 N. However, both testing and simulating values were reported at 5700-6300 N by the previous studies [10,11]. However, in their studies, the artificial soft tissue was used and the position of a load cell slightly different from this study.

The peak force with having the soft tissue was shown in Fig.6. The impact force from the model B was less than the model A by about 29%. It was due to present of the soft tissue resulting to the deceleration, absorption and distribution of the force during an impact.

The impact forces of Model C and D, however, were about 1,546 and 1,177 N which slightly differed from the FEM simulated values at 1,927 and 1,424 N, respectively. The difference was about 381 N for model C and 247 N for model D. With the results from model C and D, it was found that the hip protector type-II had a better performance than the type-I. This was due to it had a hole at the center of the PP hard shell which force had no longer transferring directly to the bone but distributing to the area nearby. When the weight was dropped to this model (model D), most of the impact force was shunted to all area of the hard shell as well as by a natural rubber. The residual force was transmitted through the soft tissue and the femur but it was very less. Therefore, the trochanter site that hadn't have the hard shell received less force than other areas but this was not the case for type-I of model C.

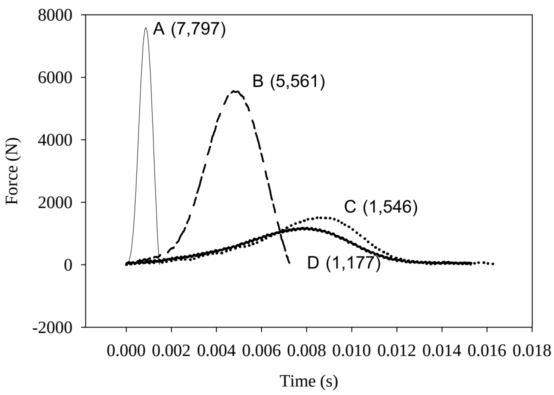

Fig.6 Force responses from testing of model A-D (number in the bracket refers to the maximum values)

The designed hip protectors of type-I and type-II in this study reduced the impact force to below 3,100 N of the estimated fracture threshold. Therefore, both types of the hip protector can be effectively used for protecting a hip from fracture but they need some development. In addition, it was found that the impact force from testing was not significantly different from the simulation by the FEM as shown in Fig.7. Hence, the FEM was confirmed that can be used successfully to design and develop a new model hip protector.

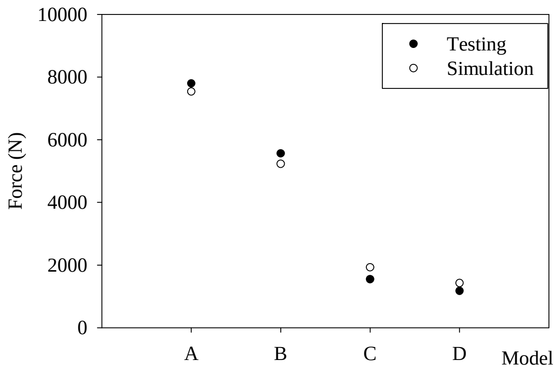

Fig.7 Comparison between the results from testing and simulation

Comparing of impact forces from testing and FEM, it was found that both results differ in a range of 200-400 N. These differences may cause from the precise of the testing apparatus the uncountable friction and the ideal setting of FEM

4. Conclusion

This study was to compare the impact results of different hip protection models from simulation and the testing. The results showed that the impact force from FEM similar to the impact force from the testing apparatus. The basic designed models of hip protectors, in this study, successfully reduced the impact force below the hip fracture threshold. Hence, this study can bring about the performance design of the hip protector using FEM in the future.

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