A review of hip fracture analysis subjected to impact loading

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Abstract. A hip fracture not only affects the body but it also the economy of human. Before improvement and prevention have been developed, research need to be done in order to identify the factors that contribute to the hip fracture. The objective of this paper is to review on past studies that related to factors that influence the impact of force to the proximal femur and to evaluate the relation of the results between computational analysis and experimental method. Experimental and finite element (FE) method is the main approaches to predict the hip fracture of the femur bone. There are several parameters of impact force such as body mass index, the thickness of soft tissue, impact velocity and stiffness of human body that influence the effect of hip fracture during fall. Based on the previous study, force and stiffness result between FE analysis and experimental have shown good correlation. For that reason, the FE method can be applied to predict future result related to the hip fracture research.

1. Introduction

A hip fracture usually a result of short, low trauma fall, car crash, sport injuries. Fall in older adults particularly to the side contributes to the highest rate of fractures[1–3]. These fractures happen when the force exerted on the bone is stronger than the bone itself. The force is found to influence the extent of the fracture. The direction of force varies, as the falling is an unpredictable event [4]. Because of this, the pattern of the fracture are varies with different type of fall [5]. According to the Feldman and Robinovitch [6], the result from the experiment shows that 98% from fall that struck on pelvis affects the hip area. Fracture of the hip does not only effect on mobility and quality of life but also contribute to the increase risk of death; the rate of mortality one year after hip fracture in the elderly patient is reported to be as high as 23% [7].

With the intention to provide a better understanding of hip fracture so that appropriate prevention and improvement can be made, researchers from previous studies have conducted an experiment and computational model of various conditions [3–5,7–12]. Most of these research related to the stress distribution [13,14], impact force, initiation of failure [3] and strain distribution [4]. In order to determine the accurate result, a constant value of factor that influences the magnitude of peak force that affected the proximal femur during falling were used. Prior to determining the effect of force on the proximal femur, some parameters need to be identified namely impact velocity, boundary condition (position of the femur), body condition (effective body mass, stiffness of pelvic, thickness of trochanter soft tissue), loading condition (falling height) and geometry of femur. These factors are important in order to better
understanding the mechanism of hip fracture because of its influence the compression rate of the proximal femur [15] as reported by previous studies [3,16–21].

Body mass and falling height of the body directly influence the peak force. However, these effects differ with the level of cushioning by soft tissue and clothing on the femur [9]. For Korean, the highest risk of hip fracture for both sexes was correlated with low BMI [22]. As for soft tissue, Stephen et al [23] stated that the peak force reduced linearly as the thickness of soft tissue increased. The objective of this paper is to review past studies related to factors that influence the impact of force to the proximal femur and to compare the results based on computational analysis and experimental method.

2. Method to predict the hip fracture
Computational analysis and experimental method are found to be the main approaches to predict the hip fracture of the femur bone. During the experiment, most of the tests employed drop test method where the body mass hit the top of pelvis spring. The pelvis mass bypasses the spring and directly impact the soft tissue and femur [1,3,15,18].

Most analysis that related to hip fracture from computational method is using finite element analysis (FEA) [19,24–28]. FEA has been widely used in the medical science field where FEA been applied to investigate the mechanical behavior of human body structures. With the objective to develop a finite elements model of the proximal femur, several steps and conditions need to be defined [20]. The first step is creating the finite element model of the femur by identifying the geometry of the bone as well as the thickness of soft tissue. Most of the research nowadays used CT scan to determine the accurate geometry and material properties of the femur. Accuracy is important because elasticity and density of bone are one of the parameters on the load transfer mechanism. Otherwise, the data may lead to wrong conclusions as a result of the data inaccuracy. Secondly, the mesh of finite element model need to be created after the geometry of the bone is prepared. Then only the finite element analysis can be proceed further. To conduct analysis properly, mechanical properties, loading and boundary condition such as the position of femur, position and value of peak force need to be defined. These parameters may vary as they highly depend on the goal of the research.

3. Parameter of Impact Force
In order to investigate the effect of the impact force on the femur bone, some parameters that contribute to the degree of impact force need to be defined. By identifying and understanding these parameters, more accurate results can be obtained and a further improvement in the prevention of hip fractures can be done.

3.1. Body Mass Index (BMI)
BMI is dependent on the weight and height of the human. Every value of body mass index influences the energy and impact force delivered to the proximal femur during the fall. A person with a high body mass index is less likely to have hip fractures because of falling [29] where the result from past studies shows that mean BMI of participants with fracture and without fracture of the femur are 22.6 and 25.5 respectively [30]. People with a weight loss of 10% considerably exaggerated the chance of hip fractures among folks aged 65 years and over [21]. This is because energy absorption reduced due to less degree of padding of trochanteric soft tissue [9].

3.1.1 Effective body mass
Effective body mass can interpret as a half of body weight. The value of effective body mass that been used in the experiment from several researcher are in the range 32-35kg [3,8]. While the value of effective body
mass in finite element analysis is from 20.9 kg until 35 kg \([1,31]\). Nevertheless, the past study of direct measurement in a young participant that related to the effective mass body shown the range of mass is from 24.1 kg to 50 kg \([16,32]\).

### 3.2. Stiffness of Pelvis

In order to predict the impact force that hit the femur bone, the estimation of pelvis stiffness is required. This is because, during fall that involves direct impact, impact load is dependent on the effective stiffness of the body to receive the degree of force before it impacts the femur bone \([12]\). However, some of the previous studies show that during impact, pelvis stiffness only has minimum effect on peak force. From the previous study, a constant value of pelvis spring that act as pelvis compliance are 50kN/m \([1,15]\). This value also supported by international consensus statement for hip protector testing \([15]\).

### 3.3. Thickness of trochanteric soft tissue

Skin, fascia lata, muscle, fat, and the trochanteric bursa act as soft tissues that cover the greater trochanter \([23]\). The thickness of trochanteric soft tissue is the overall sum of soft tissue that surrounds the greater trochanter. It influences the distribution and magnitude of the force as it acts as a protector of proximal femur during fall. Based on the result of previous research, the thickness of soft tissue over trochanteric was correlated to the peak force during sideways fall\([3,12]\). If the thickness of soft tissue is set as a big value, then the ability of energy absorption will increase and dissipate more energy \([9,12]\). As the thickness of trochanteric soft tissue increase, reduce the body’s effective stiffness, consequently reducing the peak force applied to the hip amid an impact. In a variety of experiment, the chosen value of trochanteric soft tissue thickness was 19mm as it is in the range of standard in hip protector testing protocol \([15]\).

### 3.4. Velocity of the Impact

Several factors influence the impact velocity of falling. One factor is the height and weight of the human body. The result of the research shows that the velocity of impact increases as the height and weight of person increase \([9]\). Another factor is the reaction of the body when people about to fall such as using their hand. This results in the time interval between pelvis impact and hand \([6]\). The increase in time interval reduces the impact velocity during falling. On the other hand, the impact force decreases during falling as the impact velocity decreases. The range of impact velocity in several previous study for experiment and finite element method were from 2 m/s until 3.17 m/s \([1,6,8]\) and 1 m/s until 3m/s \([3,13,14]\) respectively. Generally the range of impact velocity for computational and experiment were 3.35-4.34 m/s and 2.94-3.6 m/s respectively \([15]\). However, the value of impact velocity during falling is dependent on the boundary condition of the experiment and FEA.

### 4. Comparison between Experimental and Finite Element Method

The objective of this study was to compare the result between experimental and computational method related to the hip fractures cases. This comparison is to validate the capability of finite element analysis in predicting the result that related to the hip fracture. Both FEA and experiment results show no significant different in stiffness or yield load between augmented and control specimen\([7]\). In fact, the result of force and stiffness between experimental and FEA have shown good correlation\([22,32]\). However, there are several result that show a moderate correlation between experimental and FEA result for bone stiffness and energy absorption\([1,27]\).

The differences of correlation between FEA and experiment result, as mention here is due to the different boundary condition and different in finite element models such as material properties, geometry and velocities. Size of meshing element and geometry are also additional factors that influence the FEA results.
obtained. In general, the FEA method is reliable and able to accurately predict the future result related to hip fracture research. This will help to reduce the cost, as the procedure and item of the experiment are very costly.

5. Conclusion
In this paper, information related to the method, parameter of impact force and the relationship between finite element analysis and experimental result have been gathered and discussed. These studies show that the combination of complex parameter of human body condition can influence the impact force during falling. However, the geometry of the proximal femur is complex. There are several different requirements in order to run the experiment and finite element analysis. However, the previous studies show that the results of both methods have good agreement with each other. This can be concluded that finite element analysis can be apply to predict hip fracture cases in future.

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