RELATIONSHIP BETWEEN IMPACT ANGLE AND DEFORMATION OF PROXIMAL FEMUR IN FALLING

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INTRODUCTION

Bone mineral density(BMD) has proven to be an effective predictor of fracture risk. By predicting a fracture risk from an individual's BMD, one can estimate the denominator of the risk factor. Loading angle and strain rate, which are independent of density, might also affect the structural capacity of the femur[Courtney et al., 1994; Pinilla et al., 1996]. Nonetheless, in previous studies, there have not been attempts to match these two factors in falling condition.
Therefore, the purposes of this study were (1) to develop the impact testing system to simulate the falling condition; (2) to investigate the change of deformation pattern of proximal femur considering the influence of impact angle; and (3) to conduct the traditional static test for two-legged stance to compare with the deformation pattern caused by the impact

MATERIALS and METHODS

Prior to impact test using a fresh-frozen human femur(male, 31) prepared by the procedure of Carter et al.[Carter et al., 1980], we developed surrogate-pelvis and pendulum impact tester to simulate the falling condition and then conducted the experiments changing the impact angle of proximal femur[Robinovitch et al., 1991]. Also, in order to analyze the relative risk due to falling to normal situation in proximal femur, we did the static test simulating the two-legged stance condition.(Table 1) (Figure 1)

Table 1: Strain gage number and location

Strain gage location		
Subcapital region	Femoral neck	Femoral shaft
1. Inferior	**4**. Inferior	**7.** Posterior
2. Superior-Posterior	**5.** Superior-Posterior	**8.** Anterior
3. Superior-Anterior	**6.** Superior-Anterior	

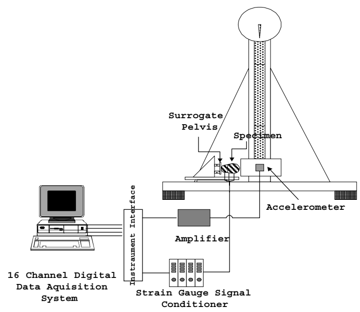

Figure 1: Schematic diagram of impact test

RESULTS

The maximum impact force and velocity were 1,050±35N, and 0.91±0.04□, respectively.
The axial and transverse strain patterns at each impact angle were presented in Figure 2 and 3

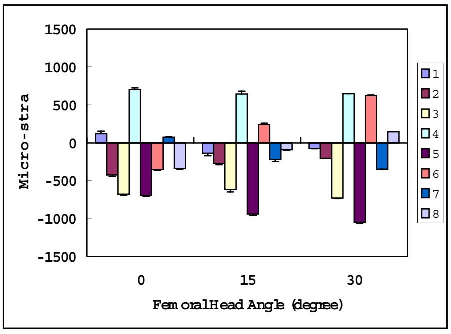

Figure 2: Axial strain patterns of each location at different impact angle

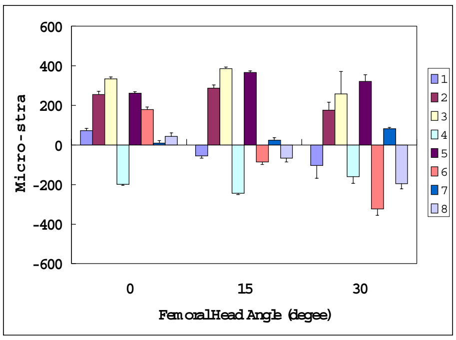

Figure 3: Transverse strain patterns of each location at different impact angle

During the present experiment, the neutral axis was calculated by the simple matrix operation[Biewener, 1992]. The angle of the neutral axis to horizontal line in femoral head were 66.04°, 53.04°, 57.43°, and 29.05°for 0°, 15°, 30°impact angle, and two-legged stance, respectively(Figure 4). In femoral neck, they were -70.88°, -47.43°, -36.46°, and -80.36°, respectively(Figure 5).

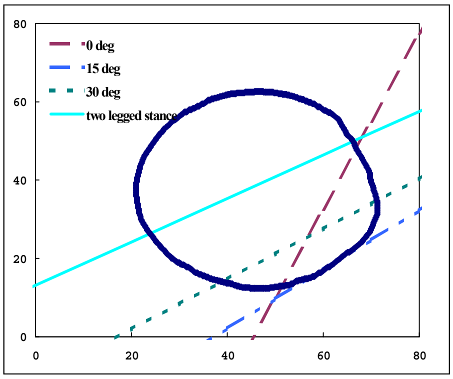

Figure 4: Changes of neutral axis in femoral head

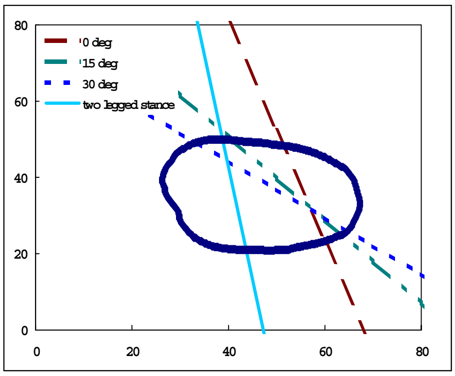

Figure 5: Changes of neutral axis in femoral neck

DISCUSSION

The object of our study is to investigate the relationship between impact angle and deformation pattern in falling. The test was conducted on the same specimen below the yield stress to prevent its permanent deformation at each impact. In spite of these limitations, we have some favorable aspects.
One of the strengths in our study is that the present impact test is to investigate the effect of impact direction on the deformation of proximal femur during fall. Unlike previous mechanical test protocols,[Courtney et al., 1994; Pinilla et al., 1996] we developed the impact test system composed of impact pendulum and surrogate pelvis. It is an essential aspect at impact study that the impact system properly simulates the dynamic response of the hip during a falling of body. So, we adjusted our test system to simulate effective mass, stiffness, and damping of a typical male pelvis during a fall of the hip. Another strength is that based on these data, more accurate finite element model will be constructed to predict the failure of femur. Earlier computational models have not fully predicted hip fracture due to the lack of experimental data. So our findings will be helpful comparing with the previous models. Finally, the deformation patterns computed in our study are clinically useful. The computed strains are considered more useful for the comparison of injury occurrences with biomechanical responses. Furthermore, fundamental mechanics for loading and bending induced by a primary impact will be useful in regards to the various modes of femoral fracture.

SUMMARY

We have developed the impact test system and observed that a slight variation in impact angle affects deformation pattern of the proximal femur significantly. Along with bone mineral density, geometry, and trabaecular morphology, impact angle and strain rate are thus another important factors affecting the structural capacity of the proximal femur. However, unlike the intrinsic, bone-related properties, impact angle depends on the falling direction, which needs additional researches of falling itself in the etiology of hip fracture.

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