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Comparison Fatigue Life Time Prediction of Femoral Ball and Condyle Bovine Trabecular Bone

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Abstract. Fatigue of trabecular bone under physiological loading can give new insight on fatigue life and behavior under certain human habitual activities. The aim of study is to characterize the fatigue strain on trabecular and compare the strain in fatigue condition of different two anatomic parts. Loading condition were applied depends on normal human walking forces acting on hip. Hip contact loads were used for simulated the human gait while walking were chosen from the maximum load on hip and 75 % of that loading transferred to the trabecular for stress range 16 % - 55 % from that loads. The result showed different anatomic parts on trabecular adapt different physiological apparent loading due to orientation in human anatomic axis and give different hysteresis loop with the largest variation in strain. The huge different in strain gap after 10^4 cycles in both anatomic part is show that the femoral ball is more capable than condyle to sustain the prolonged loading.

Keywords: cancellous bone, trabecular bone, fatigue.

1. Introduction

Fatigue studies have been reported many researchers on trabecular [1-4]. Additionally, both human [1] and bovine [4] has been well defined their fatigue behavior under compressive by conventional fatigue loading method. However, fatigue associated with physiological loading on trabecular bone still remains undiscovered. Trabecular bone structure has been proven that it takes almost 75% of external loading [5] which is the most of the loading were absorbed by trabecular bone as load bearing. Fatigue behaviors on trabecular bone are induced by many cases of physiological human activities which can contribute to stress fracture from rigorous activity for athletes and fragility fracture in aging such osteoporosis [6]. This condition in fatigue depend on real situation related to trabecular load adaptation and it fission from cortical loading is still limited in determine the precise mechanism of trabecular failure.

Repetitive physiological loading in routine activities referring to human gait on hip forces [7] and their contribution to fatigue behavior still remain unstudied. In such, their habitual effect on fatigue in certain human gait condition would alter loading magnitude and pattern introduced new insight of physiologic activities on trabecular fracture. In fact, activities such walking or stair climbing under high frequency of load cycle on bones, fatigue life of trabecular would be shorted as it adapt most of load from cortical [5].

Previously, study of the stepwise cyclic loading amplitude on trabecular bone has been reported in study of damage accumulation and effect on fatigue life [8]. Although type of loading applied to the trabecular sections were different between various human gaits, it might be difficult to determine in certain real loading situation on bone. In connection to this situation, proximal femoral load related to hip contact forces [7, 9] has been studied to estimate the maximum peak forces on hip and it contribute to new loading method to be applied on fatigue analysis in trabecular structure for this study.

In this study, loading were applied resulted from human gait analysis on femur transferred to the trabecular bone and were analyzed to mimic the normal walking condition. The aim of this study is to characterize the dynamic mechanical properties on trabecular bone fatigue behavior under axial cyclic compressive in physiological normal human walking loading condition and compare the properties between two anatomic part. This study should give new insight of path physiological finding and clinical implication on gait activities which can be reduced to prevent fatigue of bone under certain case of physiological loading condition.

2. Methodology

2.1. Sample preparation

Bovine bone specimen was extracted freshly on hind limb of femoral ball and condyle with diamond saw at slow speed. Specimen then were prepared into rectangular shaped in precision cutting machine (Allied Techcut, USA) with 0.58 mm thick diamond-resin bonded wafering blade with custom modification to make sure accurate dimension at minimum speed 150-250 rpm in continuous copious water irrigation to prevent heat-related damages [10]. Specimen then was stored after every process in airtight small bag and temperature was making sure -18°C to -20°C [1] all the time. Prior to testing, marrow was cleaned from specimen using an ultrasonic cleaner (Crest ultrasonic, model P11000SR, USA) [11] with a chemical detergent (Pumicized, Gent-l-kleen, USA) [12]. Water jet, air jet and vacuum suction was used to remove excessive marrow and water until it obvious dry.

2.2. Mechanical testing

All fatigue tests were performed using an Instron universal testing machine (Model 8874) with 10 kN maximum load cell. For testing, six specimens (10 mm ×10mm × 27 mm in length) were aligned perfectly in custom jig for better vertical oriented. Specimen was placed in end cap and fixed via hot-melt adhesives (DGHL, model HL-E, China) cover about 5 mm depth in end cap. Fatigue test were performed on load control sinusoidal waveform and the load applied were adapted from hip contact force in human gait analysis [6] or the estimation of body weight were assumed 85 kg on average. External hip contact force loading transmitted about maximum 75 % [5] to the trabecular bone were manipulated into loading magnitude which were applied on specimen. Through all, 16 % of maximum trabecular load was chosen for lower stress and 55% for upper stress in fatigue test [1] which were simplified in sinusoidal waveform rather the actual gait analysis. All fatigues tests were performed at frequency 2 Hz in which simulated and was calculated refer to the normal human walking motion amplitude during gait.

3. Results

Fatigue tests with simulated the physiological loading of human activity in trabecular bone was showed the hysteresis loop pattern for certain selected cycles. Specimens were tested until 250,000 cycles and testing was stopped. Fig. 1 and 2 represent the result of hysteresis loop from different anatomic part of femur ball and condyle. The inclination of each hysteresis cycle in both anatomic parts was different in maximum strain and modulus even at the same cycles was chosen to failure. The variation in strain changes in condyle part is higher than the femoral ball in each determined cycles. Maximum strain evolution in determined stages of cycles was demonstrated in Fig. 3 between two different anatomic parts. Maximum strains are drastically increased in femoral condyle if compared to femoral ball in after more 10^2 cycles.

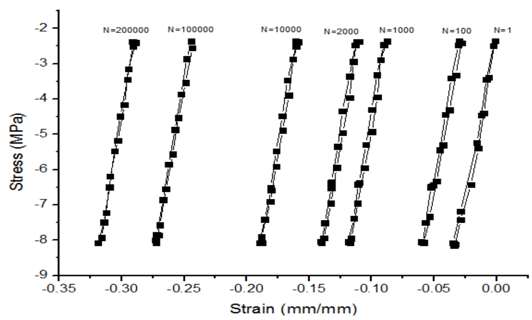

Fig. 1: Stress strain hysteresis for bovine femoral ball.

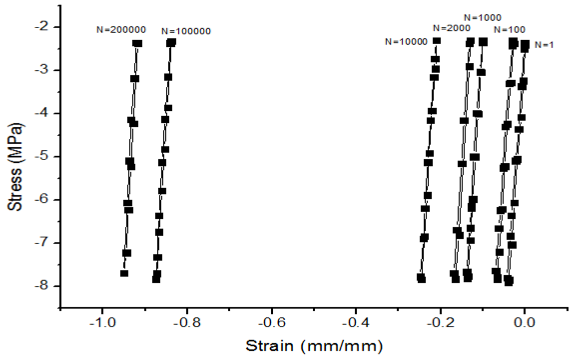

Fig. 2: Stress strain hysteresis for bovine femoral condyle.

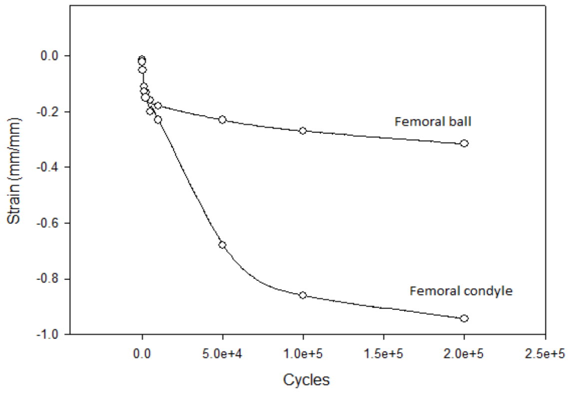

Fig. 3: Maximum strain as a function of numbers of cycles in two different anatomic parts.

4. Discussions

Fatigue with the apparent physiological loading which simulated the human gait during normal walking was performed in vitro on trabecular bone. Fig. 1 and 2 has been demonstrated the cyclic stress hysteresis and strain behavior was investigated through two different anatomic part of femur. Failure defined at the strain ranged 1.05 – 1.4 % changes. After 10^4 cycles, femoral condyle part showed that the strain drop drastically indicates the stochastic reduction in modulus and strength to sustain the physiologic load. The low bone density of condyle region resulted the highly reduction in strength and modulus than femoral ball. This condition denoted naturally that the strength trabecular structure also related to bone volume fraction and apparent density.

This condition showed that the femoral condyle is more likely responsive to failure than femoral ball. From Fig. 3, femoral ball show clearly that the trabecular structure can sustain any longer than condyle from failure and capable to absorb more loading situation in gait before failure initiation. In fact, compared to condyle which supposedly adapt axial compressive loads dominantly, femoral ball sustain multi-axial physiological loading attached from hip. From gait analysis, it has been showed the proximal femur overtaken most of the load in hip contact. As a result, it can adapt the maximum load till overt failure. In summary, fatigue physiological loading adapted from gait analysis which simulates human daily activities loads can be studied to real life estimation on fatigue life prediction on different anatomic parts.

5. Acknowledgements

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