Effect of the Lacuna Distribution on Stress and Strain in Single Osteon

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Abstract—In order to understand bone behaviour and bone failure behaviour, this study aimed to investigate stress distribution and strain developed in a single osteon with a different number of lacunae when a compressive load was given. Finite element (FE) analysis of single osteon was developed, one osteon with no lacuna (Model A) and three osteon models with a different number of lacunae (10 lacunae = Model B, 8 lacunae = Model C, 6 lacunae = Model D). The single osteon is developed as a semi-circle due to symmetric structure, with the presence of Haversian canal at the centre in each model. Stress distribution in Model B, Model C and Model D were shown to yield the highest stress at the lacuna near the given load and Model A was shown to yield maximum stress near the Haversian canal. The maximum strain of Model B, Model C and Model D were measured at the ellipse lacuna near the load while the maximum strain of Model A was shown at lamella near Haversian canal. These investigated results for the stress distribution and strain in the osteon can be used in the study to determine the yield region in osteon in bone fracture study.

Index Terms—Lacuna; Single Osteon; Stress Distribution; Strain.

I. INTRODUCTION

Bones are complex hierarchical structures that form support in vertebrAE. Studies suggested that bone microstructures are related to the micro-crack formation and growth in the bone [1-2]. The bone structures at different levels eventually affect how it reacts to the pressure given to its structure. At nano-scale structure, bone is made up of organic material, inorganic material and water. At sub-micro-scale, the mineralised collagen fibrils were arranged in a circumferential direction to make up lamella (3-5 μm), which eventually form the osteon. Also, there is a structure known as a lacuna, the ellipse-shaped cavity, which located between thin and thick lamellae interface. Lacuna contains bone cells (osteocytes), and the dimension of the structure is 22 μm × 9 μm × 4 μm. At micro-scale, lamellae are arranged into concentric cylinders forming osteons approximately 200 - 300 mm in diameter. Each osteon has a canal at the centre, called a Haversian canal, through which the blood vessels run into the bone [3-5].

A study done by Brien et al. [6] found that osteons act as barriers to crack in the bone. However, some of the cracks that can break into the cement line, which made the osteon to act as a weak point and facilitate crack propagation in the bone. Apart from that, the study suggests that micro-cracks propagation will eventually stop once they reach the region of high osteon density in bone. Najafi et al. [7] also found that micro-crack growth is affected by the osteons and the crack follows a path between the osteons. This path is also affected by the distance between the osteons. A study by Ebacher et al. [8] shows the unique structure of lamellae, and the osteons distribution within the bone play a role in controlling the process of bone fracture. From the literature, it can be concluded that the osteon plays an important role in maintaining the bone toughness, give strength to the bone and also delaying the bone from fracture.

Apart from that, the sub-micron structure of osteon, which is lacuna, was suggested to act as a stress riser in the osteon. A study found there is strain amplification at lacuna in osteon of the bone. Reilly [9] suggested the lacuna may act as a site for micro-crack formation. The local strain that is high enough can cause the initiation of micro-crack in the osteon structure [10]. According to Currey, stress is the resistance in the object that prevents it from deforming, and strain is the measure of deformation in the object [11]. Previous studies of the osteon were limited to experimental observation [7-10] and the progressive damage in single osteon considering the presence of lacunae in the model [3, 11]. The relationship between the micro-cracks formation and bone microstructure has not yet been fully understood and need further quantitative investigation.

This present work aims to identify the effect of lacunae number in the single osteon on stress distribution and strain concentration at a given load. In this study, finite element (FE) analysis was adopted for the analysis of stress distribution in single osteon with a different number of lacunae distribution, but the locations of lacunae were fixed in every model. Even though these studies neglecting many other properties of a cortical bone microstructure such as cement line and an interstitial matrix, this model gives the understanding of stress and strain yield region in the single osteon with the presence of the lacuna.

II. FINITE ELEMENT MODELING

The osteon was built as a heterogenized model, which consist of 17 thick lamellae and 17 thin lamellae. The thickness of thick lamella and thin lamella were set to 2.4 μm and 0.8 μm respectively. The centre of the osteon was left empty, which resemble the presence of Haversian canal. The model was displayed as semicircle due to its symmetrical structure as shown in Figure 1. The radius of the canal was