THE EFFECTS OF SURFACE CURVATURE ON BIOMECHANICAL BEHAVIOUR OF ARTICULAR CARTILAGE

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This report was submitted in fulfillment of the requirement for the award of Bachelor of Degree of Mechanical Engineering with Honours (Structure & Materials)

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DECLARATION

"I hereby declare that the work in this report was my own except for summaries and quotations which have been duly acknowledged."

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ABSTRACT

Osteoarthritis (OA) occurs even more frequently nowaday on the middle aged group, the senior citizen group and even the youngsters will also affected by this disease. Osteoarthritis was characterised by the pain of joint and malfunction of the joint, and then in further stage will be the joint contractures, muscles atrophy and limb deformity spine. The main causes for Osteoarthritis to occurs will be due to the degeneration of articular cartilage. Therefore, it is important to understand the behaviour of the cartilage. In the previous experimental studies, the cartilage are often been assumed to be flat. However, the actual cartilage surface in human synovial joint will be in curvature shape. Hence, this report will determine the effect of surface curvature on cartilage behaviour by using the indentation test and finite element analysis. Finite element model with several radii of surface curvature will be used to compare with the analysis of model with flat surface. Based on the comparison result, the percentage of difference by comparing the smallest cartilage surface of convex 15 mm radius with the flat cartilage surface for contact pressure is 10 % while for the pore pressure will be 6 %. This shows that the surface curvature of cartilage does affect the biomechanical behaviour of cartilage.

ABSTRAK

Pada hari ini, Osteoartritis (OA) bukan sahaja berlaku lebih kerap atas kumpulan pertengahan umur, kumpulan warga emas, malah remaja juga terjejas oleh penyakit ini. Osteoartritis boleh dicirikan oleh sakit sendi dan kerosakan sendi, dan pada peringkat selanjutnya Osteoartritis boleh dicirikan daripada contractures sendi, otot atrofi dan kecacatan tulang belakang. Punca utama untuk Osteoartritis berlaku ialah disebabkan kerosakan tulang rawan. Oleh itu, permahaman tentang tulang rawan adalah penting. Dalam eksperimen sebelum ini, tulang rawan sering diandaikan sebagai permukaan rata. Namun, permukaan rawan yang sebenar pada sendi sinovia manusia ialah dalam bentuk lengkung. Oleh itu, laporan ini akan mengkaji tentang kesan kelengkungan permukaan terhadap ciri-ciri rawan dengan menggunakan ujian indentation dan Finite element analisis. Model finite element dengan beberapa jejari kelengkungan permukaan akan digunakan untuk membandingkan dengan analisis model dengan permukaan rata. Berdasarkan keputusan perbandingan, peratusan perbezaan antara permukaan cembung rawan terkecil 15 mm jejari dengan permukaan rawan rata untuk tekanan sentuhan adalah 10% manakala bagi tekanan pore adalah 6%. Ini menunjukkan bahawa kelengkungan permukaan rawan akan memberi kesan atas ciri-ciri biomekanik rawan.

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LVDT – Linear variable differential transformer

MRI – Magnetic resonance imaging

OA – Osteoarthritis

PBS - Phosphate Buffered Saline

FE - Finite Element

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Osteoarthritis is one of the cartilage diseases which occur due to the abnormal biomechanics of cartilage. More than 20% of the population in Malaysia may have Osteoarthritis. Osteoarthritis will causes pain and stiffness, especially in the hip, knee, and thumb joints. One of the main causes of osteoarthritis is due to the degeneration of articular cartilage. Articular cartilage is a white dense connective tissue which covers the bone ends within a diarthrodial joint in human body. The function of articular cartilage is to provide frictionless bearing in a joint while it uniformly transferring loads on underlying bone in order to prevent high stress concentrations. Therefore it is essential to study the behaviour of articular cartilage in order to prevent the degeneration of cartilage.

1.1 PROBLEM STATEMENT

In previous studies, articular cartilage are often assume to be flat surface while study the biomechanical properties. However, the actual articular cartilage possessed curve surface in human joint. Therefore, this project will study the effect of cartilage surface curvature on the biomechanical behavior of articular cartilage.

1.2 OBJECTIVE

The aim of this project is to study the effects of cartilage surface curvature on biomechanical behavior of articular cartilage.

1.3 SCOPES

The scope of the project includes:

- To establish the procedure to determine the thickness of articular cartilage.
- To study the effect of the cartilage surface curvature to the contact stress and pore pressure during indentation test using Finite Element Analysis.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter will discussed about all the literature review that being study and refer for this report. In this chapter, the definition for Osteoarthritis, synovial joint, articular cartilage will be discussed. The method use in previous study in examining articular cartilage will also be include in this chapter.

2.1 OSTEOARTHRITIS

Osteoarthritis is a condition that affects human's joints by degenerate the joint cartilage and the underlying bone. The surfaces within human joints become damaged so the joint doesn't move as smoothly as it should. Osteoarthritis occurs most commonly from middle age and onward. It will cause pain and stiffness at the cartilage surfaces, especially in the hip, knee, and thumb joints. The difference of normal joint and joint with osteoarthritis is as shown in Figure 2.1.

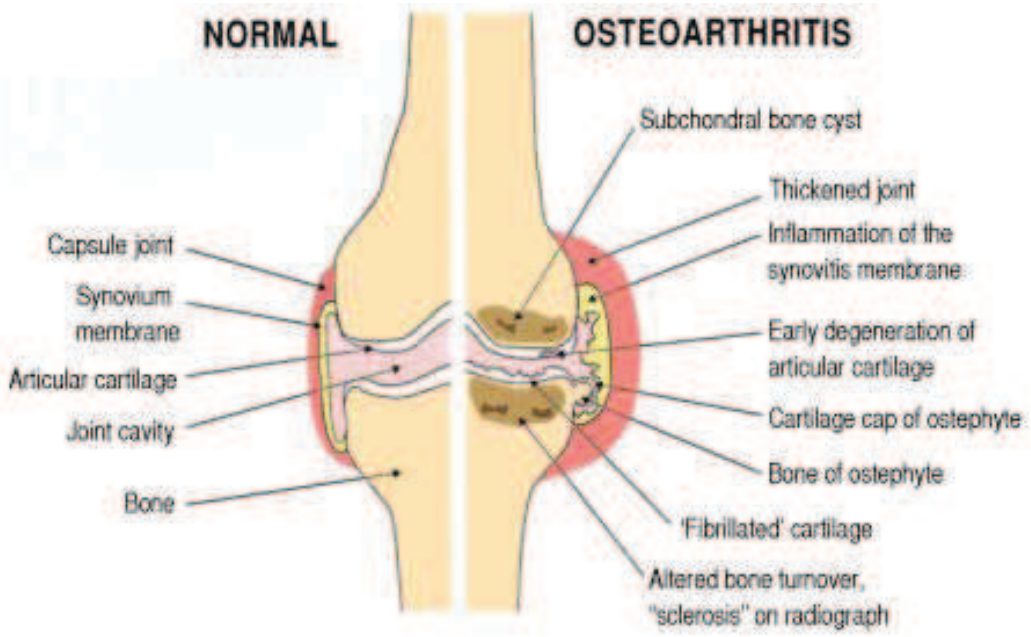

Figure 2.1 Comparison of Normal Joint and Joint which have Osteoarthritis

As the age of a person increases, the amount of water in the nucleus pulposus decreases, which reduces the cushioning effect of articular cartilage *(Sarzi-Puttini et al, 2005)*. However, stated that articular cartilage can also be damaged due to several reason such as osteochondritis dissecans, post traumatic, immobilization. The damage on articular cartilage also can occur on youngster, especially people in sport and damage cause by osteochondritis dissecans. By the way, the abnormal bio-mechanics of cartilage plays an important part in the development of osteoarthritis *(Kwan et al, 1986)*.

2.1.1 CAUSES

The factors that cause osteoarthritis included overweight, joint injury, genetic defect in joint. However, the degeneration of cartilage will be the general factor to cause osteoarthritis. The cartilage rub against each other and the friction occur will cause the cartilage that cover the end of bone become more roughens and become thinner. The

body will try to repair the damage but sometimes the cartilage can become so thin that it does not cover the ends of the bones. Therefore the bones rub against each other and start to wear out. The loss of cartilage, the wearing of bone and the bony spurs can change the shape of your joint, forcing the bones to be out of their normal position. By the way, the reduction of the concentration of proteoglycans, breakdown of collagen network as well as an increase in the water content and softening of the tissue will cause osteoarthritis *(Julkenen, 2008)*.

2.1.2 DIAGNOSIS

Osteoarthritis is usually diagnosed based on the symptoms and the physical signs that the doctor finds when examining the joints. The doctor will check for the properties such as the tenderness of joint, the creaking sounds, excessive fluid, movement and instability of joint, muscle thinning, etc. Some other methods also can use to diagnose the osteoarthritis, such as X-rays and Magnetic resonance imaging (MRI) scans. *Barry et. al. (2014)* use MRI scans to study the radiographic of knees. *Marsh et. al. (2013)* use both MRI scans method and X-rays method to investigate the knee cartilage thickness to compare their results. X-rays are the most common tools to confirm osteoarthritis. Although the image of cartilage will not show up on x-rays images, but they will show the changes of the bone. While MRI scans is rarely to be used on diagnosis of osteoarthritis but MRI scans can give further information that causes the joint to defect. MRI scans uses radio waves and strong magnetic field to show the image of bone and soft tissue, such as cartilage.

2.1.3 TREATMENT

Osteoarthritis has no cure but some medications can be used to help relieve pain. Physical therapy (PT) or occupational therapy (OT) can be used to help improve strength and function of the joint. However, when the pain is frequently occur or mobility and daily activities become difficult, then surgery may be considered.

2.2 ANATOMY OF SYNOVIAL JOINT

Synovial joint are the most common joint in mammal's body. Most of the joint in human body are synovial joint, such as hinge joint at knee and elbow, condyloid joint at wrist, saddle joint at thumb, etc. Same as the most of the other joints, synovial joints can achieve movement at the point of contact of the articulating bones. Synovial joint will include some component such as articular cartilage, joint capsule, synovial fluid, ligament, menisci and bursae as shown in Figure 2.2 *(Shier et. Al., 2008)*. Joint capsule is the tubular structure that has two distinct layers; the outer layer is made up of dense fibrous connective tissue while the inner layer is a shiny vascular membrane called the synovial membrane. Synovial fluid is a clear viscous fluid secreted by the synovial membrane for the lubrication of the joint. Ligament is the bundles of tough collagen fibers that serve to strengthen the joint capsule. Menisci are the disks of fibrous-cartilage found in some synovial joints that serve as shock absorber. Bursae will be the fluid-filled sacs that cushion and support the movement of tendons within a synovial joint.

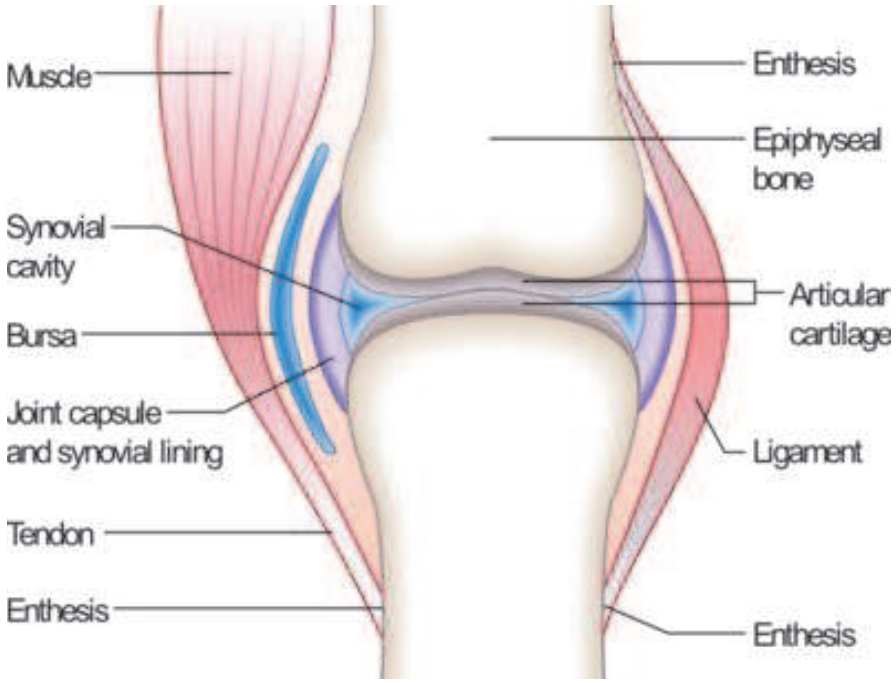

Figure 2.2 Nomenclature of Synovial Joint

2.3 ARTICULAR CARTILAGE

The main types of cartilage include fibrous cartilage, elastic cartilage and hyaline cartilage. Fibrous cartilage can be found in such areas as between vertebral discs of the spinal cord. Elastic cartilage can be found at the outer ear, nose, and larynx. Hyaline cartilage which also referred to as articular cartilage covers joint surfaces and additionally may be found in the shoulder, rib cage, knee and hips as well. The general nomenclature of articular cartilage is as shown in Figure 2.3.

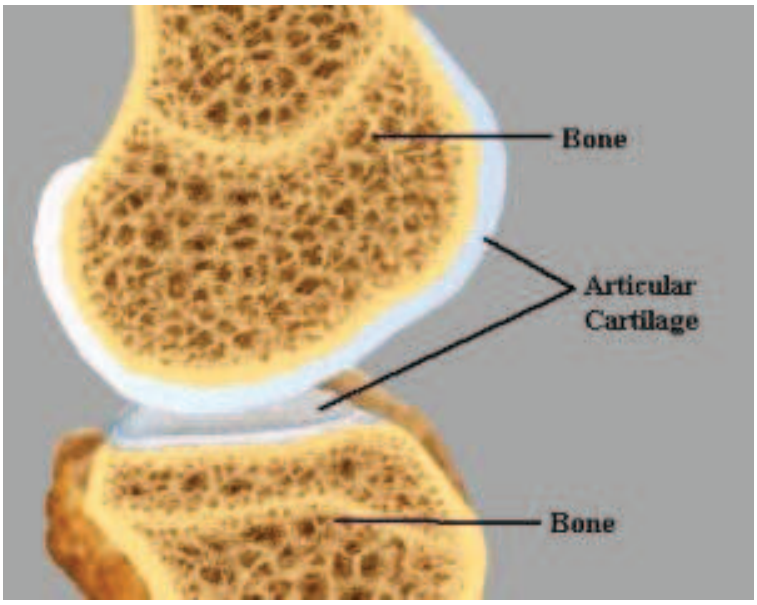

Figure 2.3 Articular Cartilage

2.3.1 STRUCTURE AND COMPOSITION

Articular cartilage is a white dense connective tissue which covers the bone ends within a diarthrodial joint *(Kwan et. Al., 1986)*. It is a soft, highly hydrated and permeable tissue. About 80% of articular cartilage is form by water. Articular cartilage has 3 main structures which is collagen, proteoglycans and interstitial fluid *(Julkenen, 2008)*.

There are 3 layer of collagen in articular cartilage, which is superficial zone, middle zone and deep zone as shown in Figure 2.4. This 3 layer are being differentiated by the orientation of the collagen fibrils. The superficial layer is to be described as a tension resisting diaphragm and is demonstrated by the tendency of articular cartilage to curl when released from the subchondral bone. In the middle layers, chondrocytes attain a rounded or spherical shape, proteoglycans content increases and the collagen fibers decussate to provide an oblique transitional network intermediate between the tangential