CORRELATION OF BIOMECHANICAL PROPERTIES OF ARTICULAR CARTILAGE BASED ON MAGNETIC RESONANCE IMAGING (MRI) IMAGE

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This report is submitted in fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering (Structure and Material)

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DECLARATION

I declare that this project report entitled "Correlation of Biomechanical Properties of Articular Cartilage Based On Magnetic Resonance Imaging (MRI) Image" is the result of my own work except as cited in the references

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Date	:	27 JUNE 2016

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Materials).

Signature : ....

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Date : 27/6/2016

DEDICATION

To my beloved mother and father. My three little brothers. My little sister.

ACKNOWLEDGEMENT

In the Name of Allah, the Beneficent, the Merciful

In completing this report, I would like to express my gratitude and thankful to everyone who have involved helping me.

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ABSTRACT

The World Health Organization (WHO) estimates that every one out of ten of the world's population over the age of 60 years suffer from osteoarthritis (OA), Usually, joints of patient that suffer OA show signs of degeneration on their cartilage. However, there is no early detection on OA. The objective of this study is to estimate the correlation between the biomechanical properties of a cartilage and MRI image. The general methods included in this study were obtained based on MRI image of articular cartilage using MRI Scanner. Then, the image processing method is using the MATLAB Software and the average value of intensity of articular cartilage by layers obtained to correlate it with elastic modulus and permeability. Both correlation shows positive trend against the grayscale intensity of articular cartilage.

ABSTRAK

Data yang dikeluarkan oleh Organisasi Kesihatan Dunia menunjukkan bahawa satu daripada sepuluh penduduk dunia yang berumur 60 tahun ke atas menderita penyakit sendi lutut. Hal Ini berlaku disebabkan kemerosotan fungsi tulang rawan yang bertindak sebagai pelincir untuk sendi. Namun demikian, pengesanan awal terhadap penyakit ini masih belum konkrit sepenuhnya. Sehubungan dengan itu, kajian ini menjalankan pencirian sifat biomekanik bagi rawan menggunakan imej MRI. Metod yang digunakan dalam kajian ini adalah pengimbasan imej MRI dan penganalisaan imej menggunakan perisian MATLAB. Seterusnya, analisis kuantitatif diperolehi melalui ujian korelasi antara lapisan rawan dengan kebolehtelapan dan modulus elastik rawan. Hasil kajian menunjukkan hubungan yang signifikan antara kedua-kedua pembolehubah ini. Tuntasnya, kajian ini berupaya menonjolkan potensi MRI dalam mengesan penyakit osteoartritis sekaligus membawa kepada satu titik tolak dalam penyelidikan rentas disiplin.

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LIST OF ABBEREVATIONS

AC	Articular Cartilage
ADSP	Advanced Digital Signal Processing
FKE	Faculty of Electrical Engineering
MRI	Magnetic Resonance Imaging
NMV	Net Magnetisation Vector
OA	Osteoarthritis
RF	Radiofrequency
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The World Health Organization (WHO) estimates that every one out of ten of the world's population over the age of 60 years suffer from osteoarthritis (OA), and eight out of ten people with OA have limitation of movement and one quarter people will have difficulty in performing any major daily activities (World Health Report Archives, 1995-2000). The number of person experiencing OA still did not decrease and until today there is no effective treatment available to get fully recover in OA. Patient may suffer from stiffness and inflammation due to OA. Usually, joints of patient that suffer OA show signs of degeneration on their cartilage. However, there is no early detection on OA. Patients are usually diagnosed when they have already suffered from OA. Once they have suffered from the disease, there is no effective treatment available. There are only treatments to reduce pain and slow down the degeneration process available. Therefore, this study will be a significant to unresolved issue regarding osteoarthritis.

1.2 Problem Statement

In osteoarthritis, there is still no effective treatment available to cure the disease. There is also no specific methods to detect the disease earlier before it becomes worst. All of this happens as there are still many unresolved issues regarding to osteoarthritis. Previous study shows the different thickness of cartilage in indentation test in order to examine the biomechanical behaviors of cartilage. This research will correlate the biomechanical properties of an articular cartilage using Magnetic Resonance Imaging (MRI) to obtain the biomechanical characteristic of an articular cartilage.

1.3 Objective

The purpose of this study is to examine the correlation between the biomechanical properties of a cartilage and MRI image.

1.4 Scope of Project

The scope of this project is to:

- Scan articular cartilage using low-field Magnetic Resonance Imaging (MRI)
- Determine grayscale intensity of articular cartilage from MRI image
- Obtain the grayscale correlation between grayscale intensity and biomechanical properties of articular cartilage.

CHAPTER 2

LITERATURE REVIEW

2.1 ANATOMY OF SYNOVIAL JOINT

Referring to human body, there are three types of joint when characterized to its structure. There are fibrous joint, cartilaginous joint and synovial joint. Synovial joint is the type of joint that provides full movement to the bones unlike fibrous joint which did not provide any movement and cartilaginous joint which only provide some movement. There are six types of synovial joint; ball and socket, planar, hinge, pivot, condyloid and saddle. In this study, it emphasize on ball and socket joint that is located at the hip and shoulder of a human skeleton. The location of all synovial joint are as referred in Figure 2.1. Based on figure, it also show the types of movement provided by each joint. There are pivot joint located between the vertebrae, hinge joint located at the elbow, saddle joint between the trapezium carpal bones, ball and socket joint located at the hip and shoulder, condyloid joint located between radius and carpal bones of wrist, and plane joint between tarsal bones at the ankle. Synovial joints contain synovial fluid which allows movement between bones. Previous research (Cooke et al, 1978) states that one of the manifestations of osteoarthrosis is wear of the articular surfaces. The factors thought to influence this wear include the forces to which the joint is subjected and a breakdown of the joint lubrication. The composition of tissue of a joint capsule are depending on three factors which is the development origins, loading experience and age (Ralphs and Benjamin, 1997).

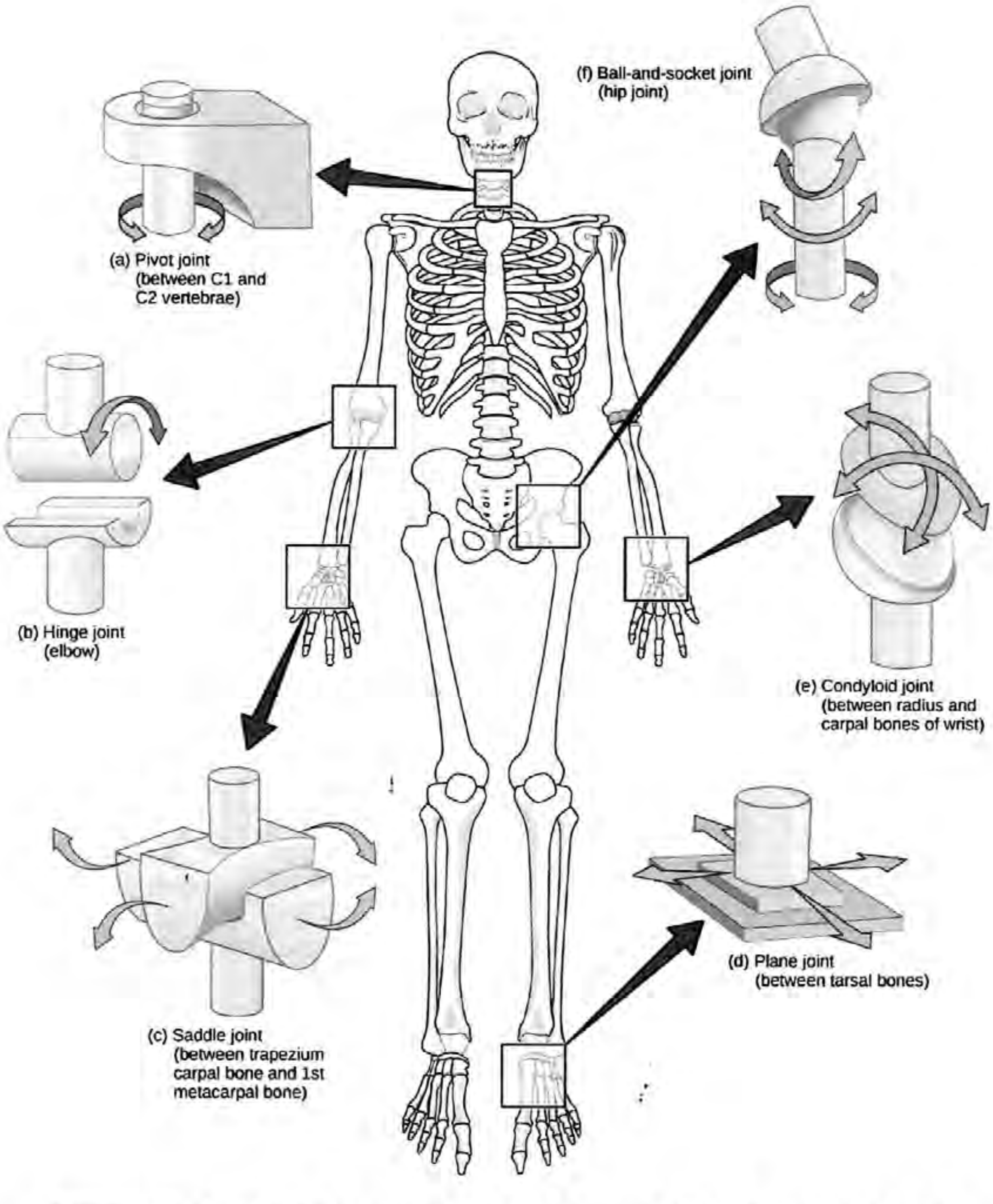

Figure 2.1: Locations of synovial joint in a human skeleton. Adapted from Boundless.com, (2013)

Figure 2.2 shows the anatomy of synovial joint. The interaction between articular cartilage, fluid and bones take place inside the synovial membrane area. The articular cartilage covers the bone area that exposed to the opposite direction bones. Synovial fluid has two main functions which are to provide nutrition to the articular cartilage and to act as lubrication in order to ensure the aid of mechanical function.

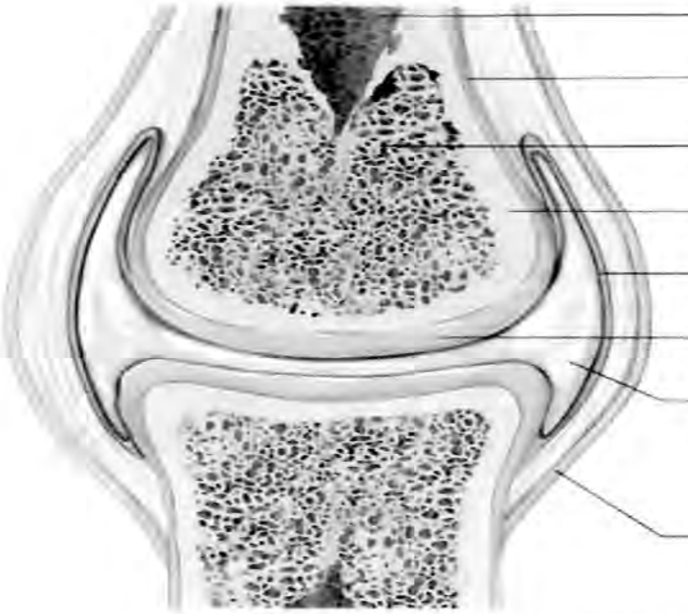

Figure 2.2: Anatomy of Synovial Joint

2.2 ARTICULAR CARTILAGE

Cartilage is a connective tissue found in various parts of body such as joints, rib cage, ear, nose, bronchial tube and intervertebral disc. Articular is the term used in joint. Articular cartilage (AC) is a cartilage that usually found in joints area such as knees and hips. Figure 2.3 shows the exact location of articular cartilage in a joint structure. Articular cartilage is a necessary evil in musculoskeletal pathophysiology. Evil because once damaged, the tissue initiates a downward spiral into degenerative state (French and Athanasiou, 2003). Although AC is a well functioned tissue that is very important in daily activities, it is also a tissue that once damaged it will continue to degenerate as there is still no cure.

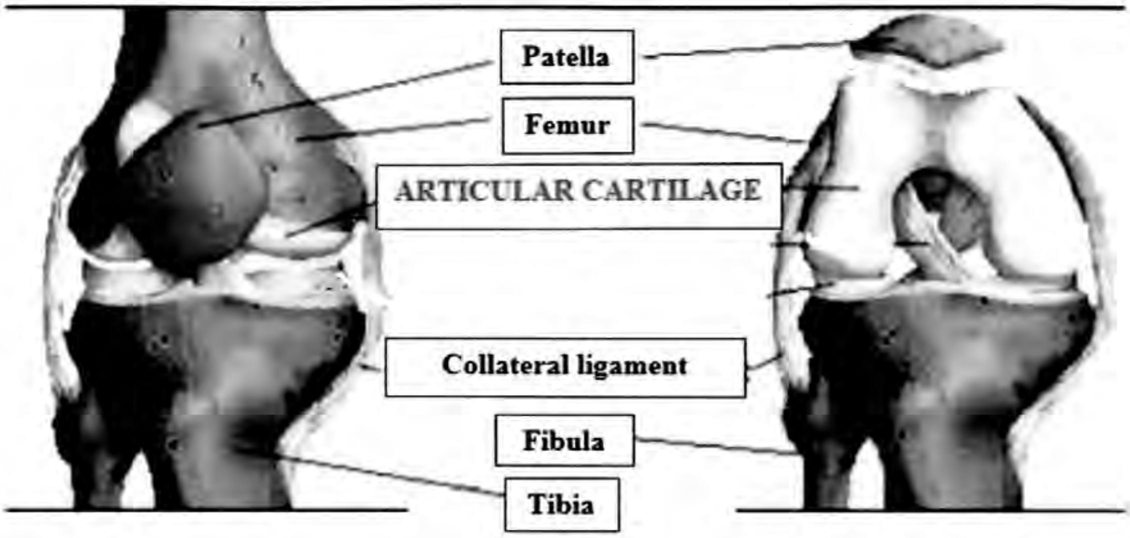

Figure 2.3 Location of articular cartilage in a joint structure

2.2.1 Structure and Component

The structure of a cartilage is usually a thin layer of elastic and wear resistance component which is surrounds the joint bones. Cartilage tissue is largely composed of an extracellular matrix that is produced by chondrocytes (Conaghan and Sharma, 2009). Articular cartilage is a tissue mainly composed of collagen, proteoglycan and interstitial water. 80 % of cartilage net weight is the composition of water itself. Unlike any other cartilage, articular cartilage does not contain any blood vessels, nerves or lymphatic. All the complex interaction and constituents play an essential role in the mechanical property of cartilage.

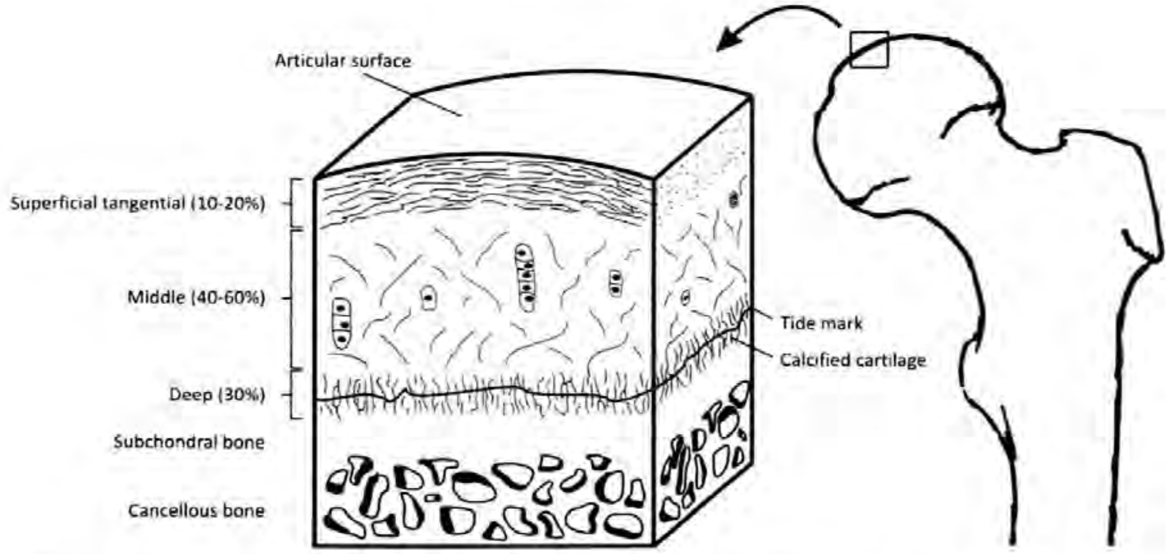

Figure 2.4: Schematic diagram of layers of articular cartilage. Adapted from Intech Open (2013)

Cartilage consists of two phases; solid phase and fluid phase. Collagen and proteoglycan are the solid phase while water is known as the fluid phase. Referring to figure 2.4, there are four different zones of layered structures. In order from the outer layer to the inner layer nearest to the bones are the superficial zone, middle zone, deep zone and zone of calcified cartilage.

The superficial joint is the articulating surface that provides a smooth gliding surface and resist shear. It has the highest collagen content compared to the other zones; the collagen fibrils in the zone are densely packed and have a highly ordered alignment parallel to the articular surface (Andrew. D et al, 2005). It is understandable that the layer with the most collagen content is very crucial as it act as a wear resistance substance. In this way, cartilage able to resist the compression because of the physicochemical characteristics of the proteoglycan gel trapped between the collagen meshwork. Collagen fibers are vital in playing this roles (James and Thimoty, 2011). This zone makes up about 10% to 20% of the cartilage thickness. The middle zone possess until 40% up until 60% of the cartilage volume. The collagen of the middle zone are packed loosely and aligned obliquely to the cartilage surface. It has less organized arrangement compared to the superficial zone.

The deep zone of the cartilage possesses 30% of the cartilage volume. Compare to the other cartilage layers, this layer have the highest compressive modulus. The water concentration of this layer is the lowest and proteoglycans contain are the highest. The last layer of the cartilage that is the closest to the bone is the calcified cartilage. The significant function of this layer is only to separate the bones with the cartilage as the calcified is rest directly on the subchondral bone.

2.2.2 Functions of Articular Cartilage

Articular cartilage is a specialized connective tissue covering joint surfaces that enables the function of the joints effectively by reducing friction and allowing load distribution. The principal function of articular cartilage is to provide smooth, lubricated surface for articulation and to facilitate load transmission with low frictional coefficient (Andrew D. et al, 2004). Despite ability of AC to withstand wear it is essential for a cartilage to maintain its condition to prevent any degeneration of its component causing any joint disorder.

The predominant method of lubrication of articular cartilage during joint motion is elastohydrodynamic lubrication. This occurs when pressure in the fluid film deforms the articular surface, increasing the surface area and reducing escape of fluid from between the surfaces as they glide over each other. Other methods of lubrication include boundary lubrication, boosted lubrication and weeping lubrication. For boundary lubrication, it is which lubricating glycoprotein prevents direct surface contact of the articulating surfaces. Meanwhile for boosted lubrication the solvent part of the lubricant enters the articular cartilage which leaves the hyaluronic acid complexes acting as a lubricant and for weeping lubrication it describes the ability of articular cartilage to exude or imbibe fluid as the joint surfaces glide over each other providing self-lubrication. The efficiency of these lubrication processes means that wear in synovial joints is minimal. In short, the main function of cartilage is to provide lubricant to resist wear.

2.2.3 Mechanical Behavior of Cartilage

The mechanical behavior of an articular cartilage provide the cartilage to function well. Articular cartilage is hyaline cartilage on the articular surfaces of bones which is low in friction and wear resistance (Pearle et al., 2005). The low friction property of a cartilage allow the cartilage to function properly. The articular cartilage has mechanical properties of the fluid transport and dispersing properties of the cartilage. These properties are what made the cartilage to be nearly frictionless and able to absorb shock due to movement.

In terms of mechanical, cartilage is a soft, viscoelastic tissue and strong imaging and anisotropic properties (Potter and Koff 2012). There are various type of mechanical properties that can be determined. For articular cartilage sample, the tissue Young's modulus, aggregate modulus, dynamic modulus and Poisson's ratio can be determined in unconfined compression. These mechanical parameters can be determined with stress relaxation, creep or dynamic loading schemes.

The mechanics of articular cartilage is primarily related to biphasic theory. Biphasic is also known as poroelastic for the character of material that is elastic and porous at the same time. There are three major internal forces act within the loaded tissue. There are stress developed within the deformed collagen–PG solid matrix, pressure that is developed within the fluid phase, and frictional drag acting between the fluid phase and the solid phase as they flow past each other. All of these three internal forces act in concert to balance the externally applied force, thus giving rise to a viscoelastic effect.

There are several theories explaining the behavior of articular cartilage in the presence of load conditions, summarized in computer models that include swelling process and the properties of the anisotropic structure of collagen. Previous researches suggest that displacement of cartilage is larger during tension load compared to compression load but pressure experienced during compression is higher that tension loads (Nancy et al, 2012).

2.2.3.1 Permeability and Elastic Modulus

The mechanical properties are believed to be dominated by the proteoglycans due to their osmotic contribution (Korhonen et al, 2003). During osteoarthritis, the mechanical properties are known to change. Research by Werner (2002) states that the damage level can be correlated to the elastic modulus and permeability. High damage level shows high permeability and low elastic modulus.

Previous study suggest that the elastic modulus value ranged from 0.45MPa until 0.8MPa. Compared to engineering materials such as steel and woods which each has elastic modulus of about 10GPa and 200Gpa, cartilage have possess lower stiffness. For cartilage permeability, previous study states that the value typically ranged from $10^{-15}\ M^4/Ns$ to $10^{-16}\ M^4/Ns$ (Mansour, 2009)

The ability of cartilage to support load through interstitial fluid pressurization is depend on its low hydraulic permeability. Hydraulic permeability describes the ease of fluid flow through a material, which for articular cartilage is governed by the extracellular matrix. Degenerative changes in cartilage that occur with osteoarthritis (OA) have been correlated with increased hydraulic permeability of cartilage.

Permeability is the rate of fluid diffusion inside a porous material. Articular cartilage is considered as porous and anisotropic material. Anisotropic refers to the property of an object change with direction. The porosity of the material allows fluid to diffuse. However, too high permeability will cause damage to the cartilage due to the fluid component flowing out of the tissue when subjected to compressive loading. At the same time, high permeability is also required to allow the fluid flows inside the articular cartilage. That is why the permeability of the outermost layer of an articular cartilage is required low.

The values of permeability decreased with increased applied pressure, and also moving from the superficial to the deep layer (Boschetti et. al., 1993). This is consistent with what observed for bovine cartilage in published works (Mansour and Mow,1976 ; McCutchen, 1962).

In cartilage biomechanics, instead of Young's modulus, the aggregate modulus is often used to describe the tissue, because it can be directly calculated from the equilibrium data in a confined compression test for example the loading pressure divided by the equilibrium strain in compression direction. Elastic modulus however is the resistance of a material being deformed elastically. In the context of articular cartilage, it is not healthy for