CHARACTERIZATION OF BIOMECHANICAL PROPERTIES OF ARTICULAR CARTILAGE USING MAGNETIC RESONANCE IMAGING

WONG CHIEN HING

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SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

Signature :.....

Name of Supervisor : DR. MOHD JUZAILA ABD LATIF

Date :.....

DECLARATION

I declare that this project report entitled “Characterization Of Biomechanical Properties Of Articular Cartilage Using Magnetic Resonance Imaging” is the result of my own work except as cited in the references

Signature : .....

Name : .....

Date : .....

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ABSTRACT

Osteoarthritis is a joint disease where the articular cartilage is degenerated slowly. Articular cartilage play an important role in reduce the friction between the bone and act as the shock absorber. Therefore, this study aim to characterize the biomechanical properties by using MRI technique and the combination of experimental and computational method. The used of MRI is to observe the cartilage surface and obtain the grayscale of the image. The experimental method in this study is indentation test whereas computational method is finite element (FE) modelling of articular cartilage. In this study, the bovine hip joint was used to study the biomechanical properties of articular cartilage. Indentation test is used to study the creep behavior and thickness of articular cartilage. For FE modelling, it is used to create a FE model of articular cartilage based on the real specimen to simulate the creep indentation test. By combining both experimental and computational method, the biomechanical properties, elastic modulus and permeability can be estimated. Moreover, a correlation between the grayscale value and biomechanical properties also been done. From this correlation, it can be shown that the grayscale value has a significant effect on the biomechanical properties of articular cartilage.

ABSTRAK

Osteoartritis adalah penyakit sendi di mana rawan artikular itu merosot perlahan-lahan. Rawan artikular memainkan peranan yang penting dalam mengurangkan geseran di antara tulang dan bertindak sebagai penyerap kejutan. Oleh itu, kajian ini bertujuan untuk mencirikan sifat-sifat biomekanik dengan menggunakan teknik MRI dan gabungan kaedah eksperimen dan pengiraan. Pengunaan MRI dalam kajian ini adalah untuk melihat permukaan rawan dan mendapatkan skala kelabu imej. Kaedah eksperimen dalam kajian ini adalah ujian lekukan manakala kaedah pengiraan adalah unsur terhingga (FE) model rawan artikular. Dalam kajian ini, hip sendi lembu telah digunakan untuk mengkaji sifat biomekanik artikular rawan. Ujian lekukan digunakan untuk mengkaji kelakuan rayapan dan ketebalan rawan artikular. Untuk pemodelan FE, ia digunakan untuk mewujudkan satu model FE rawan artikular berdasarkan spesimen sebenar untuk mensimulasikan ujian rayapan lekukan. Dengan menggabungkan kaedah kedua-dua eksperimen dan pengiraan, sifat-sifat biomekanik, modulus elastik dan kebolehtelapan boleh dianggarkan. Selain itu, hubungan antara nilai skala kelabu dan sifat biomekanik juga telah dilakukan. Dari hubungan ini, ia boleh ditunjukkan bahawa nilai skala kelabu mempunyai kesan yang besar ke atas sifat-sifat biomekanik artikular rawan.

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OA	Osteoarthritis
MRI	Magnetic resonance imaging
US	Ultrasound
OCT	Optical coherence tomography
ROI	Region of interest
BMI	Body mass index
ECM	Extracellular matrix
PG	Proteoglycans
FE	Finite element
PBS	Phosphate buffered saline
LVDT	Linear variable differential transformer

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Osteoarthritis (OA) is a joint disease, also called degenerative arthritis. This disease result from the breakdown of joint cartilage. In United State (US), studies on prevalence of osteoarthritis have presented that osteoarthritis affects 13.9% of adults (25 years old and above) and 33.6% aged over 65 years, with an approximate 27 million Americans suffer from OA (Chen et al., 2012). Besides, the women have higher chances being affected by the hand and knee osteoarthritis than men, especially in person age 50 years (Lawrence, et al., 2008).

OA is a degenerative joint disease where the articular cartilage (AC) has slowly worn away or breakdown. Articular cartilage is a white tissue that covers the end of the bone. The smooth surface of the articular cartilage reduce the friction occur in the human joint. There are many causes that result in the degeneration of articular cartilage, such as injury, overweight and others. The causes can be categorized into two types, which are traumatic mechanical destruction and progressive mechanical degeneration. The traumatic mechanical destruction happens because of abnormal or excessive use and injury of the joint whereas the progressive mechanical degeneration happen because of aging.

Knees, hips, neck, lower back, fingers joint and the bases of the thumb and big toe are often affected by OA. The patient that suffered from OA will feel the pain from the joint

whenever they move. This disease will affect their daily activity such as walking and exercising.

In previous study, many imaging methods are used to diagnose OA and observe the articular cartilage. Magnetic resonance imaging (MRI), ultrasound (US) and optical coherence tomography (OCT) are the additional approaches that have improved OA diagnosis and management through enhancement in the soft tissue depiction (Braun & Gold, 2012). Among all the imaging method, MRI is the best method for the assessment of articular cartilage due to its high contrast properties.

1.2 PROBLEM STATEMENT

MRI is the best technique available for evaluate the condition of articular cartilage since it has excellent soft tissue contrast (Eckstein et al., 2006).

In most of the previous studies, high-field MRI was used to analyze the in vivo precision of MRI-based volume and thickness measurement in patients with OA (Burgkart, et al., 2001; Kubakaddi, et al., 2013).However, the potential used of the low-field MRI has yet to be explore to assess the condition of articular cartilage. Furthermore, only geometrical studies were carried out to monitor the cartilage such as thickness, volume and joint space gap. Therefore, this study aimed to investigate the used of low field MRI in the characterization of biomechanical properties.

1.3 OBJECTIVES

The objectives of this study are as follows:

1. To characterize the grayscale of articular cartilage from the low-field MRI image.
2. To characterize the biomechanical properties of articular cartilage.
3. To correlate the MRI grayscale and biomechanical properties of articular cartilage.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. The sample used in this study is bovine hip joint.
2. The biomechanical properties are only concern on biphasic elastic modulus and permeability of articular cartilage.
3. The combination of experimental and computational method are used to characterize the biomechanical properties of articular cartilage.

CHAPTER 2

LITERATURE REVIEW

2.1 OSTEOARTHRITIS

Osteoarthritis (OA) is one of the chronic health disorders that affect the human normal life when they are aged. OA is caused by the degradation of articular cartilage. The breakdown of articular cartilage will limit the movement of human such as walking, running, even moving a finger will also cause some pain toward the OA patient.

OA represents a complex musculoskeletal disorder and is a form of disability. It ranks amongst the top five causes of disability (Chen et al., 2012). Other than that, OA does not only faced older people, but younger people will also have chances to endure this disease due to genetic problem or excessive burden on the articular cartilage. According to An Aging World: 2008, many countries in Asia are aging speedily. It is estimated that in year 2008 to 2040, the proportion of people aged 65 and above over in Singapore will increase by 316%, India by 274%, Malaysia by 269%, Bangladesh by 261% and Philippines by 256% (Kinsell & He, 2009). This has shown that with the increasing of aged people, people that will suffer from OA will also increase.

Although the OA affects all the joints in the human body, the hip and knees are the joints that usually affected by OA. In fact, OA causes more than 90% of the increasing number of total hip or knee joint replacement operations worldwide (Fransen, et al., 2011). Figure 2.1 shows the difference between normal knee and OA knee.

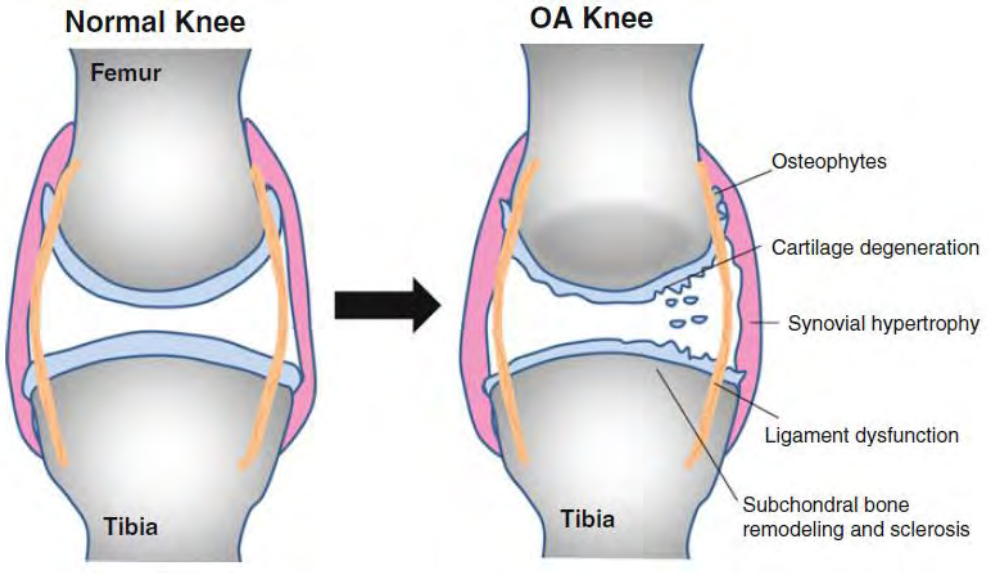

Figure 2.1: Schematic of normal vs. osteoarthritis knee joint (Kapoor & Mahomed, 2015).

2.1.1 Causes

There are some common causes for OA, such as injuries, degenerative of articular cartilage, disease and etc. The articular cartilage plays an important role in the movement that involve synovial joint, such as walking and running. Articular cartilage provides an almost frictionless sliding surface for the force to be transmitted during dynamic joint activity. When the surface of the articular cartilage is wear by the long term movement of the joint, degradation of articular cartilage will happen. This leads to the OA disease.

Aging is the main risk factor that causes OA. The biomechanical and biological changes as a result of aging are the contributing factor that causes degeneration of joint cartilage (Johnson & Hunter, 2014). Apart from aging, obesity is also a contributing risk factor for OA. A body mass index (BMI) larger than 30 kg/m^2 is considered obese, which is strongly related with knee and hand OA. Some of the metabolic and inflammatory system may affected by the people who is in obesity condition (Palazzo et al., 2016). Injuries and

overused of joint cartilage will also result in degeneration of articular cartilage. The individual with the occupation that heavily involve the knee joint double the risk of cultivating knee OA compare to the occupation that involve less physical activity (Messier, et al., 2009).

Compare to men, women has the higher risk to suffer from OA. According to Palazzo et al, women have the higher risk to suffer from knee, hip and hand OA compare to men, especially around menopause. According to study, at least 60 % of the hip and hand OA and up to 40 % of knee OA are due to genetic problem (Spector & MacGregor, 2004). While many studies focus on OA commonness, many genes have been recognized in playing a role in OA pathophysiologic pathways and thus may result to OA risk. Studies also had shown that many genes have been perceived to be related to OA.

2.1.2 Symptoms

The people who suffer from OA will have some sense of pain whenever they use their joint. Normal activity like walking, running, lifting something will also cause some pain to the OA patient. OA usually happen in hand, knee and hip. For hip OA, the groin area or buttocks will feel pain whenever the patient is moving around. Besides, there is some cracking sound when the OA patient bending their joint, such as finger and elbow. After some time or few years, these joint areas are getting swollen. The symptoms can be easily spotted through observed these joint areas. When finger and hand joint are affected by OA, some simple activities such as hold and grasp an object, writing or activities that involve using the joint will be difficult to carry out.

2.1.3 Diagnosis

For OA, there are two types of diagnosis, which are physical examination and diagnosis test. Physical examination is important in detecting OA. Each joint has unique physical examination finding (Sinusas, 2012). The testing of the range of movement and special function test such as ligament stability, meniscus and gait analysis are the basic analysis of OA (Michael et al., 2010).

Another method used to diagnose OA is by using imaging method. Plain radiography (X-Ray), Computed Tomography (CT Scan) and Magnetic Resonance Imaging (MRI) are commonly used to diagnose OA. Among these methods, MRI is able to provide more auspicious result in the assessment of cartilage status (Burgkart, et al., 2001). MRI provides an excellent soft tissue contrast and it is capable to differentiate different types of soft tissue in a joint (Soh, et al., 2014).

2.1.4 Treatments

OA is a disease that cannot be completely cured, but there are some medications to relieve the pain that OA patient suffered. Treatment for OA usually has four categories, which are non-pharmacologic, pharmacologic, complementary and alternative, and surgical (Sinusas, 2012). Non-pharmacologic often starts with physical activity. Physical activity is proven widely to decrease the pain of OA patient (Vignon, et al., 2006). According to Vignon, activities of daily life (ADL) such as housekeeping, shopping, do-it-yourself projects, gardening and recreational walking are some kind of physical activities that help in OA.

For pharmacologic treatment, Acetaminophen and non-steroidal anti-inflammatory drugs (NSAIDs) and Intra-articular steroid injections are the main treatment of OA (Taruc-Uy & Lynch, 2013). Besides, there are also some supplement for OA such as glucosamine

and chondroitin. The supplement such as glucosamine and chondroitin are effective for moderate to severe knee osteoarthritis (Sinusas, 2012).

Other than that, surgical treatment is also available for OA patient, but it is only reserved for patients whose symptoms have not responded to other treatment. Total joint replacement is an effective surgical intervention for OA treatment (Sinusas, 2012). Before surgical treatment, all OA patients should receive at least some treatment from the first two categories and go surgical treatment if only the first two categories have shown no effect.

2.2 ANATOMY OF SYNOVIAL JOINT

Synovial (diarthrodial) joints provide the body with the ability to maintain posture, and some simple movement such as walking and running. The synovial joint is covered by synovial membrane as shown in Figure 2.2. The synovial membrane release synovial fluid which acts as lubricant for the joint movement.

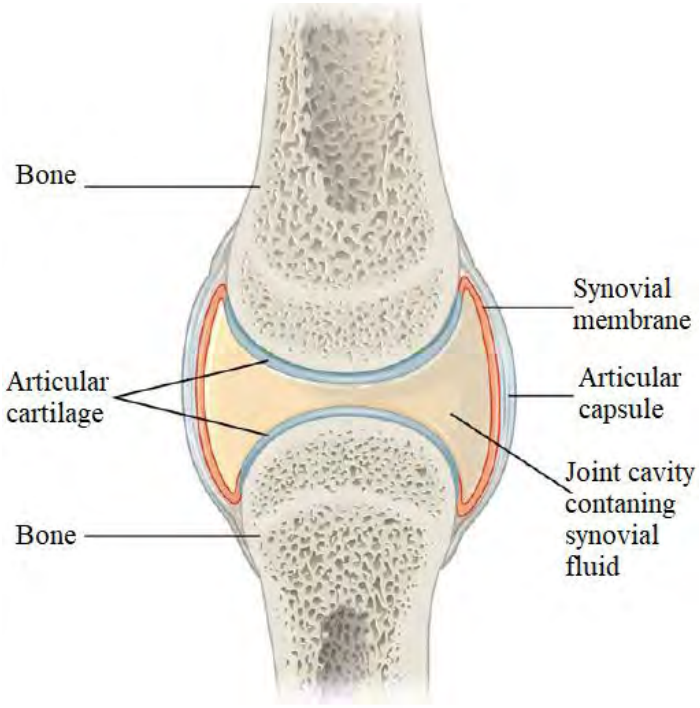

Figure 2.2: Structure of synovial joint (Heyden, 2016).

There are six types of synovial joints as shown in Figure 2.3. These include hinge, condyloid, saddle, pivot, plane, and ball and socket joint (Heyden, 2016).

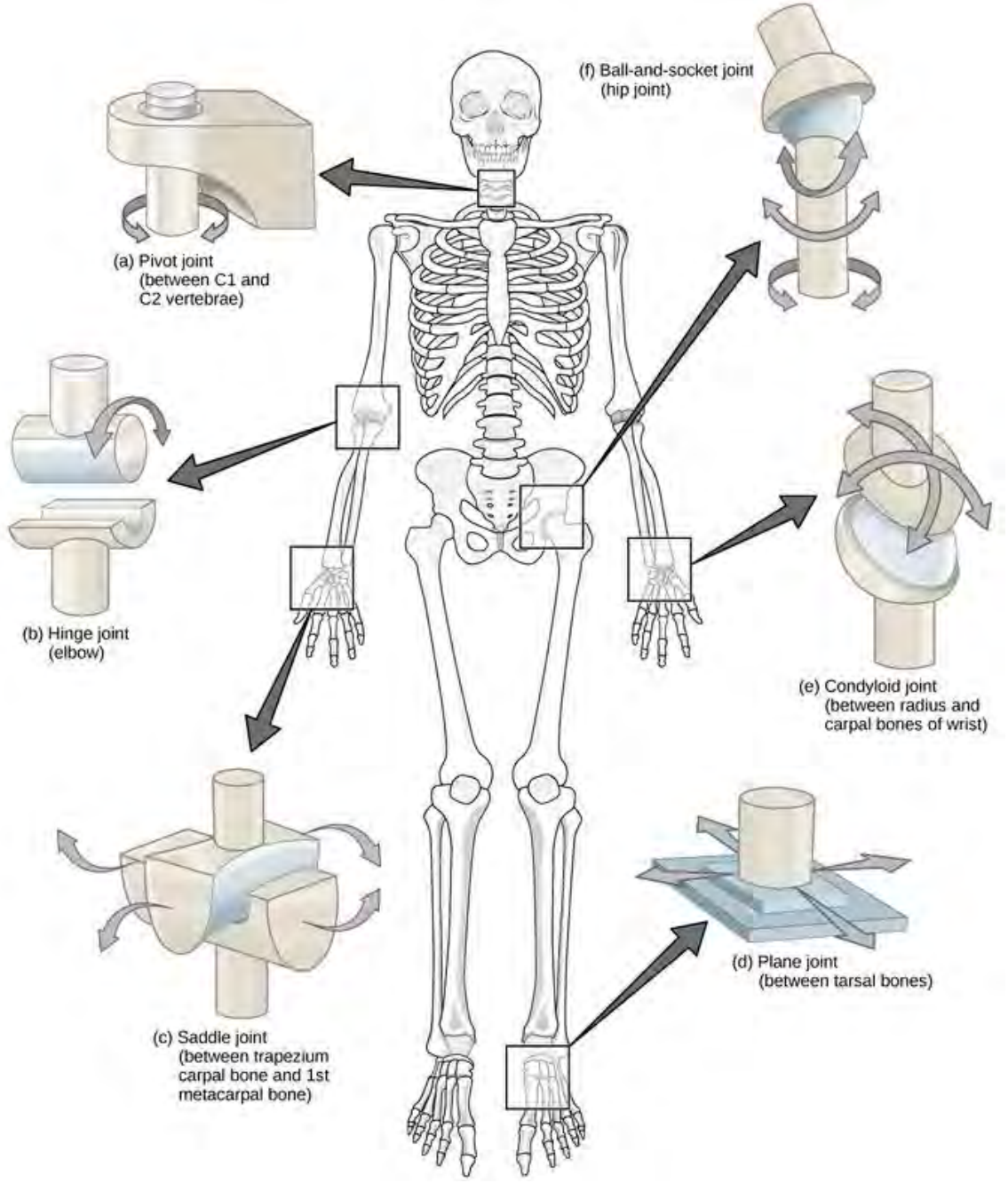

Figure 2.3: Types of synovial joint (Heyden, 2016).

Table 2.1: Description of each joint

Joint	Description	Example
Planar joint	Allow gliding movements; also called gliding joints. Not involve rotation and the range of motion is limited.	Carpals of the wrist, acromioclavicular joint
Hinge joint	Act as a door hinge, allowing flexion and extension in just one plane.	Elbow
Pivot joint	This joint allows rotational movement	Atlanto-axial joint, proximal radioulnar joint, and distal radioulnar joint.
Condyloid joint	Also called as ellipsoidal joint. Allows angular movement along two axes, such as joints of the wrist and fingers, which can move both side to side and up and down.	Wrist joint (radiocarpal joint)
Saddle joint	Allow angular movements similar to condyloid joints, but with a greater range of motion.	Thumb joint
Ball and socket joint	Allows the greatest range of motion, as all movement types are possible in all directions.	Shoulder and hip joints.

2.3 ARTICULAR CARTILAGE

Articular cartilage is a smooth and glistening bluish-white tissue that exist in synovial joint of human body. Articular cartilage covers the end of bones of a joint and it act as lubricant whenever the bones glide over each other with a small amount of friction.

2.3.1 Composition and Structure of Articular Cartilage

Articular cartilage is a biphasic material, which means that it consist of two phases, solid and fluid phase. The solid section is permeable and represented by solid matrix that consist of collagen fiber and proteoglycan molecules, and the fluid section is made up of extracellular water with dissolved ions and nutrients (Juras, et al., 2009). The thickness of articular cartilage is about 2 to 4 mm. Articular is a type of tissue that does not have blood vessels, nerves or lymphatic. It is composed of a dense extracellular matrix (ECM), which