SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis 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)"

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Date : ……

BIOMECHANICAL CHARACTERISATION OF ARTICULAR CARTILAGE ACROSS SYNOVIAL JOINT

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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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ABSTRAK

Osteoarthritis (OA) ialah sejenis penyakit degeneratif articular cartilage yang biasa dijangkiti oleh kumpulan umur sederhana dan kumpulan warga emas. Penyakit ini adalah satu keadaan jangka panjang yang boleh merosot kualiti hidup seseorang. Punca OA masih belum difahami secara penuh. Cartilage biasa dikenali sebagai bahan galas yang cemerlang sebab ia memperolehi permukaan yang licin untuk articulation dan memudahkan penghantaran beban dengan geseran yang rendah. Dalam kajian eksperimen yang sebelumnya, kebanyakan penyelidik menggunakan specimen cartilage yang kecil untuk mewakili seluruh bahagian cartilage untuk menjalankan eksperimen. Fokus utama kajian ini adalah untuk menyiasat sifat biomekanikal articular cartilage di seluruh sinovia lembu. Cartilage sendi sinovia lembu telah digunakan untuk kajian ini kerana ianya lebih mudah didapatkan berbanding dengan cartilage manusia. Dengan menggunakan ujian kasturi jalar, menjalankan ujian *in situ* di tempat yang berlainan atas articular cartilage. Method kumputer juga digunakan dalam kajian ini untuk menyiasat sifat biomekanikal articular cartilage di seluruh sinovia. Sifat-sifat biomekanikal kesuluruhan articular cartilage di seluruh sendi sinovia akan diuji dalam kajian ini. Ketebalan cartilage yang didapati dari kajian ini adalah dalam julat yang sama jika berbanding dengan kajian yang sebelumnya. FE model telah dimodelkan mengikut ketebalan cartilage yang diukur dari ujian indentation untuk mensimulasikan pore pressure dan contact pressure articular cartilage. Daripada kajian ini, ketebalan akan mempengaruhi sifat biomekanikal articular cartilage. Pore pressure dan contact pressure meningkat sekiranya ketebalan articular cartilage meningkat.

ABSTRACT

Osteoarthritis (OA) is a degenerative disease of articular cartilage, which is normally affected by middle aged and senior citizen group. This disease is a common long term condition which can result in an ongoing loss of quality of life. The cause of OA is still not yet fully understood. The normal cartilage is known to be an excellent bearing material that provides a smooth, lubricated surface for articulation and to facilitate the transmission of loads with a low frictional coefficient. In previous experimental studies, most of the researchers used the small specimen of cartilage in order to represent the whole cartilage to conduct the experiment. The main focus of this study is to investigate the biomechanical behavior of articular cartilage across bovine synovial joint. The bovine's synovial joint cartilages were used for this study because it is easier to get compared to the human cartilage. By using the indentation tests, performed *in situ* in order to measure cartilage thickness on the difference location of the articular cartilage. The computational method is also used for this study to investigate the biomechanical behavior of articular cartilage across the synovial joint. The thickness found in the present study are within the similar range when compared to the previous study. The FE model was modeled according to the cartilage thickness measured from indentation test in order to simulate pore pressure and contact pressure of the cartilage. From this study, it is concluded that thickness affects the biomechanical behavior of articular cartilage. The pore pressure and contact pressure increases as the thickness of the articular cartilage increased.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

E – Young's Modulus

H – Aggregate modulus

k – Permeability

mm – millimeter

Pa - Pascal

s – Second (time)

v – Poisson's ratio

V – Voltage

ΔP – Pressure gradient

LIST OF ABBREVIATION

ECM- Extracellular matric

GAG- Glycosaminoglycans

LVDT – Linear variable differential transformer

MRI – Magnetic resonance imaging

NSAID – Nonsteroidal anti-inflammatory drugs

OA- Osteoarthritis

PBS - Phosphate buffered saline

PGs- Proteoglycans

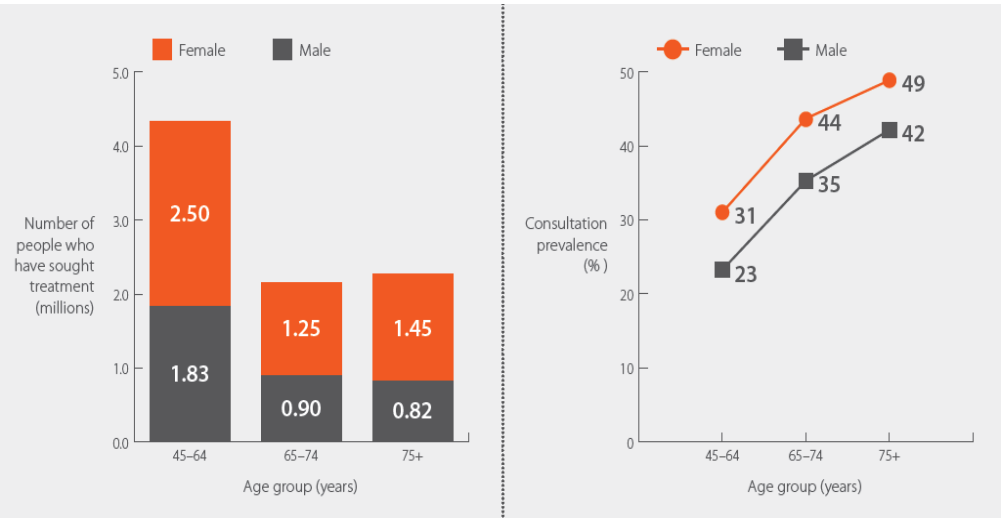
STZ- Superficial Tangential Zone

CHAPTER 1

INTRODUCTION

1.1 Introduction

Osteoarthritis (OA) is the most prevalent of rheumatic diseases and is the leading cause of pain and disability in most countries worldwide (Evangelos et al, 2001). This disease is a common long term condition which can result in an ongoing loss of quality of life. The degradation and loss of articular cartilage in synovial joint has been recognized as the main source of OA. Most of the OA disability burden is attributable to the hips and knees. Research from Arthritis Research UK Primary Care Centre shows that around 8.75 million people have sought treatment for OA in two or more sites of the body in year 2013 as shown in the Figure 1.1 (Arthritis Research UK, 2013). The prevalence of OA increases with age and generally affects women more frequently than men, with the total number of women exceeding 5 million, compared to 3.5 million men as shown in Figure 1.2 (Arthritis Research UK, 2013).



a. b.

Figure 1.1: The estimated patients in UK who have sought treatment for osteoarthritis, by gender and age group. a) By number of people, b) By proportion of people. Adapt from Arthritis Research UK, 2013.

There are various joints in human body that may be affected by OA. However, this disease is most likely to affects the hands, hips, knees, lower back and neck (Nordqvist, 2014). Knee has one of the most complex and largest joint in the body which is known as synovial joint. With the unique structure, synovial joints allow very complex movements between adjacent bones like allow the leg to bend, straighten and carries the body weight. The ends of the bone are covered by the articular cartilage which are lubricated by the synovial fluid. The articular cartilage act as a protective surface that cushions the ends of bone in the joints and allows the joint to move smoothly.

There are two main causes of the OA, which are traumatic mechanical destruction and progressive mechanical degeneration (tear and wear). The traumatic mechanical destruction is due to the abnormal use and injury of the joint while the progressive mechanical degeneration is due to aging. During OA, the smooth surface of the cartilage will becomes rough and causing irritation. If the cartilage wears down completely, thus exposing the underlying subchondral bone and the bone in the joint may be rubbing against another bone, causing damage and pain. There is no cure for OA as yet, but the pain normally relieved by either

therapeutic or operational methods. The degradation of cartilage manifests itself in the variations of its mechanical and biological properties (Carter et al., 2004). This in turn causes the cartilage susceptible to structural failures, which degrades it further.

There are plenty of researchers from multiple fields such as medicine, engineering, chemistry, material science, etc have been studying the articular cartilage at nano-, micro- and macro- levels. Most of these studies are centred around to investigate about the biomechanical properties of the cartilage. A lot of experiment had been carried out to characterize the biomechanical properties and to study the behavior of the cartilage under different experimental and physiological conditions (Mow et al., 1989; Kwan et al., 1990). Similarly, computational models have been postulated to give firm theoretical foundations to the understanding of the mechanical behavior of the cartilage (Mow et al., 1980; Lai et al, 1991). However, the lack of mechanical property information on the synovial joint cartilage posed a problem for computation modeling. Previous studies have used the data get by the small specimen but it is not known either the mechanical behavior of the specimen can represent the whole cartilage in a joint.

Therefore, the aim of this study was to develop a method to characterize the thickness and biomechanical behavior of the articular cartilage across the synovial joint using indentation test. This is to identify that the biomechanical properties of the small specimen either can represent the whole joint.

1.2 Problem statement

The behaviour of the cartilage across the synovial joint is yet to be understood because only certain locations of the cartilage were previously characterise to obtain the biomechanical properties. Furthermore, most of the previous study of articular cartilage using small specimen to represent the whole cartilage in a joint. These assumptions were inappropriate and may limit the accuracy of the result since the thickness of cartilage is different across the joint.

1.3 Objective

The objective of this study is to study the biomechanical behavior of articular cartilage across the synovial joint.

1.4 Scope

The methods used for this project are the computational modeling method and the experimental method (indentation test). The scope includes:

1 To determine the thickness of cartilage across synovial joint.
2 To establish the method to study biomechanical behaviors of cartilage across synovial joint.
3 To study the biomechanical behaviors of cartilage across synovial joint.

CHAPTER 2

LITERATURE REVIEW

2.1 Osteoarthritis

Osteoarthritis (OA) are the most common type of arthritis especially for those who reach middle age in United Kingdom. According to the National Health Service, UK, approximately 8.5 million people are affected by this disease. The Arthritis Foundation, USA, said that about 27 million Americans are affected in the year 2013. The women are more likely to be affected by osteoarthritis than men after the age of 50. This symptoms typically start after 40 years of age, and progress slowly (Arthritis Research UK, 2013). In America, arthritis and related conditions, such as osteoarthritis cost the country almost $128 billion annually in medical care and indirect expenses, including lost income and productivity. Between 1990 and 2010, disability due to osteoarthritis in the UK had increased by 16% and expected continue to grow (Nordqvist C., 2014).

The overall impact of the osteoarthritis on a person varies depending on the joints involved, the degree of pain and extent of loss of use. When the hands are affected, their daily activities will be affected, such as fastening buttons, writing and

even eating when the situation going worst. Osteoarthritis in the hips and knees will restrict mobility, limit walking, climbing, and bathing. In serious cases, osteoarthritis is a huge obstacle to people's mobility and independence, and their tone of liveliness.

2.1.1 Causes

Osteoarthritis, also known as degenerative arthritis, degenerative joint disease, or osteoarthrosis is a condition in which the joints of the body become damaged, stop moving freely, and become painful (Arthritis Research UK, 2013). Degenerative arthritis can be result from a combination of the partitioning of the joint and the body's attempted repair processes. The wearing away of the articular cartilage that covers the ends of the bones in a joint will make the two bones (tibia and femur) rubs against each other and become rough and thin. This degeneration also will affect the underlying bone become thicker and lastly grows into the joint forming bony spurs (osteophytes) which will make the gap between the bones become narrows. The inner layer of the joint capsule (synovium) may thicken and make excess fluid, causing the joint to swell, while the capsule and ligaments around the joint thicken and contact (Marlene F. et al). In severe osteoarthritis, the loss of cartilage can result in bones rubbing against each other and wearing away, as shown in Figure 2.1.

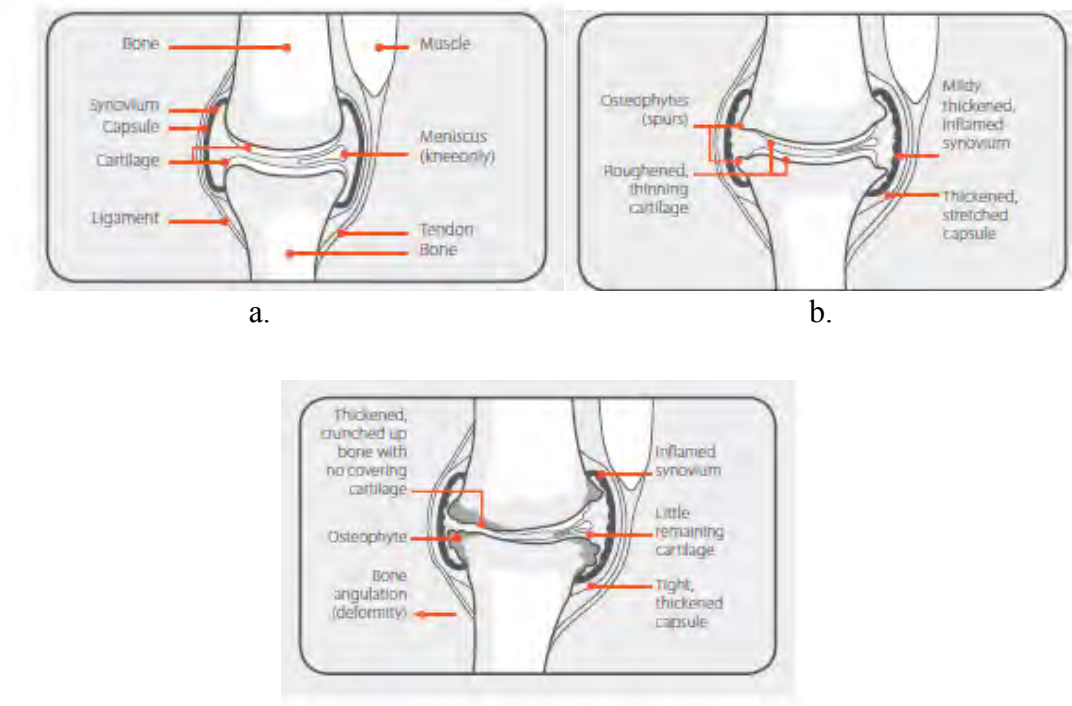


Figure 2.1: How osteoarthritis affects a joint a) A normal joint, b) A joint with mild osteoarthritis, c) A joint that has been deformed by severe osteoarthritis. Adapted from Arthritis Research UK

The causes of OA are still not yet fully understood. However, some factors that can increase the risk of getting OA are known. The common risk factors include:

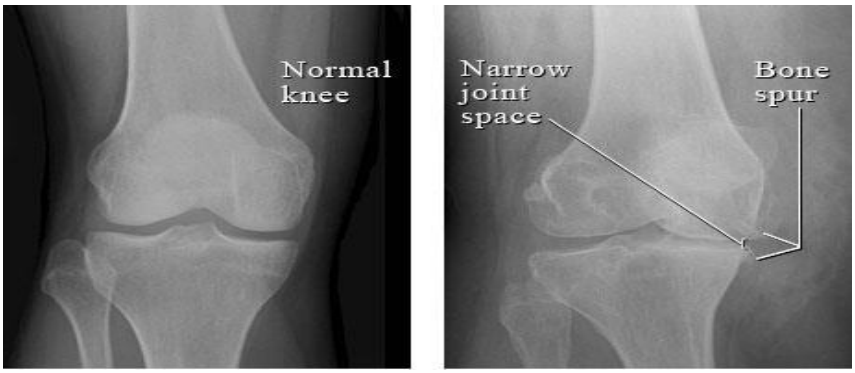
- **Age** : The chance of getting OA rises after reach age 45 because the ability to heal decreases as a person get older
- **Gender** : women taking more risk to get OA compared to men
- **Obesity**: Being overweight will cause excessive pressure on the knee
- **Previous joint injury or disease**: improper joint surgery and joint diseases may taking risk of OA
- **Heredity**: genetic mutations will make a person more likely to develop OA. It may also due to inherited abnormalities in the shape of the bones that surround the knee joint
- **Occupation**: Athletics and heavy duty workers that include a lot of activity that can stress the joint, such as kneeling, squatting, or lifting heavy weights are more likely to get OA

2.1.2 Diagnosis

Diagnosing arthritis early can prevent permanent damage. It is not always easy to diagnose and can take several weeks or months to get a definitive diagnosis. Various diagnostic tests are employed in the evaluation of OA. Basically, the GP (general practitioner, primary care physician) will ask the patient about the symptoms, as well as carrying out some physical examination and check their medical history (Sinusas *et al*., 2012). Nowadays, there is no current and definitive test that can diagnose OA yet. If the possible conditions are suspected, imaging diagnostics will be use such as plain radiography (x-rays) and magnetic resonance imaging (MRI). However, the diagnostic tests are restricted for pregnant women although the risk of radiation exposure to the fetus are small.

X-ray is the most common use by the doctor to diagnose OA. An x-ray will generate a very small amount of radiation to produce an image of the bones and tissues surrounding a joint as shown in Figure 2.2. The GP will uses the X-rays to evaluate arthritis. From the x-rays film, the GP can:

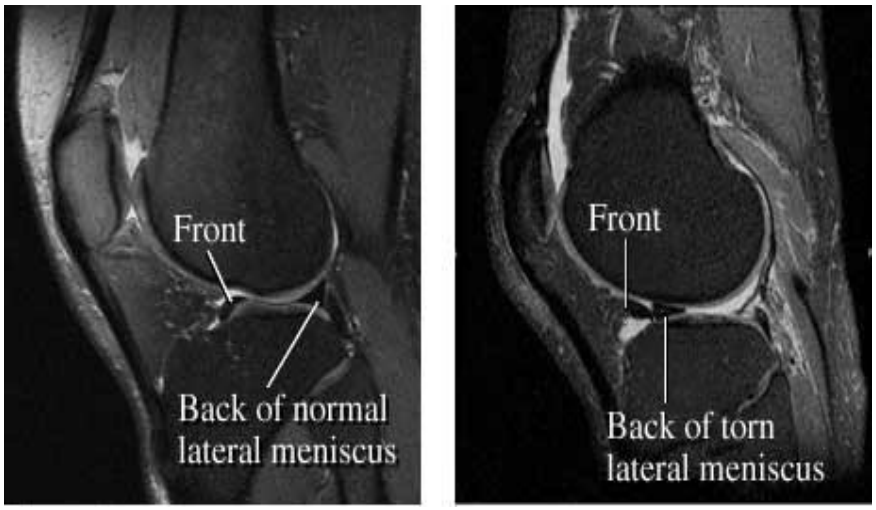
- Rule out injury or other diseases of the joint
- Have a baseline film for comparison while having treatment
- Look at the structures of the joint



a. **b.**

Figure 2.2: Examples of image of knee joint by X-rays. a) Normal knee b) bone spurs and narrowed joint space caused by osteoarthritis. Adapted from Intermountain Medical Imaging, Boise, Idaho

MRI scans may be used when X-rays do not show a clear reason for joint pain or when the X-rays suggest that other types of joint tissue could be damaged. MRI is a test that uses a magnetic field and pulses of radio wave energy to make pictures of organs and structures that are inside the body, as shown in Figure 2.3.



a. b.

Figure 2.3: Examples of image of knee joint by MRI. a) side view of the normal knee. b) Side view of knee joint with a piece of meniscus that has been torn and moved. Adapted from Intermountain Medical Imaging, Boise

2.1.3 Treatment

Treatment choices can be classify into four main categories: non-pharmacologic, pharmacologic, complementary and alternative, and surgical. In general, the safest and least invasive therapies will be the first choice before proceeding to more invasive, expensive therapies. Basically, OA patients will receive some treatment from the first two categories. If the situation of the patient declines, surgical treatment would be considered (Stephen K. et al, 2010).

2.1.3.1 Non-pharmacologic

Non-pharmacologic therapy often starts with exercise. The researchers found that the land-based exercise can relief knee pain and improve the physical function within 24 months (Thomas et al,2002 ; Frasen & McConnell, 2008) but some researchers found that the effects decline over time and finally disappear (Baar et al, 2001).

Therapeutic ultrasound is one of the non-pharmacologic treatment which is a physical therapy modality that often used in OA treatment. A Cochrane review of this modality concluded that although ultrasound therapy is almost certainly useful for some patients, but it is not a reliable or evidence-based therapy (Rutjes AW, 2010).

Another types of non-pharmacologic treatments include bracing and splinting to help support painful or unstable joints. A cane can help to support the body weight of OA patients, but it needs to be properly fitted.

2.1.3.2 Pharmacologic

Pharmacologic treatment is the treatment by using medicine such as painkillers, acetaminophen, Nonsteroidal anti-inflammatory drugs (NSAID), Opioids, steroids injection and Hyaluronic acid injection. Pharmacological treatments for OA of the knee have not been proven to change the progression of the disease, but may be practiced as a pain reliever. Basically, the Acetaminophen or painkillers (e.g. paracetamol) will be the first choice to relief the knee pain because it is inexpensive, safe and effective (Sinusas et al, 2012). The U.S. Food and Drug Administration recommends that the patient must instructed to take only 650 to 1,000 mg of acetaminophen up to four times and no more than 4,000 mg per day to avoid liver toxicity (Sinusas et al, 2012).