

**THE EFFECTS OF CARTILAGE THICKNESS ON CARTILAGE  
BEHAVIOUR IN INDENTATION TEST**

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**JUNE 2015**

### **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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**This report was submitted in fulfillment of the requirement for the award of  
Bachelor of Degree of Mechanical Engineering with Honours (Structure &  
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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 is the most common form of arthritis. Nearly one in two people may develop symptomatic knee osteoarthritis by age 85 years in United State of America. It causes pain, swelling, and reduced motion in human joints. It was characterised by joint pain and malfunction of the joint, and then in further stage will be the joint contractures, muscles atrophy and limb deformity spine. The factors that cause osteoarthritis included overweight, joint injury, genetic defect in joint, etc. In previous studies, articular cartilage is usually study only based on certain thickness and flat cartilage surface to characterize the biomechanical properties. Therefore, this project will study on the effect of the cartilage thickness in indentation experiment and computational method in order to determine the biomechanical behaviours of cartilage. The actual cartilage surface in human synovial joint will be in either convex or concave shape or came in different size, this could affect the characterised properties. Hence, this project is will be using indentation testing and computational method of ABAQUS software in determining the biomechanical behaviours such as the pore pressure and contact pressure of the cartilage caused by different thickness of cartilage. As the thickness of the cartilage changes, the pore pressure and contact pressure will be affected. It is suggested that further study of the biomechanics of human cartilage and its applications will gain from the incorporation of existing engineering techniques and the advanced evolution of new technology.

## ABSTRAK

Osteoarthritis adalah bentuk yang paling biasa dalam arthritis. Hampir satu dalam dua orang mungkin menghidapi osteoarthritis lutut gejala mengikut umur 85 tahun di United State of America. Ia menyebabkan rasa sakit, bengkak, dan mengurangkan gerakan dalam sendi manusia. Ia dicirikan oleh sakit sendi dan kerosakan sendi, dan kemudian di peringkat lanjut akan bersama contractures, otot atrofi dan anggota badan kecacatan tulang belakang. Faktor-faktor yang menyebabkan osteoarthritis termasuk, kecederaan berat badan berlebihan sendi, kecacatan genetik pada sendi, dan lain-lain. Dalam kajian sebelum ini, rawan artikular biasanya kajian yang hanya berdasarkan ketebalan tertentu dan permukaan rawan rata untuk mencirikan sifat-sifat biomekanik. Oleh itu, projek ini akan mengkaji tentang kesan ketebalan tulang rawan dalam eksperimen lekukan dan kaedah pengiraan untuk menentukan tingkah laku biomekanik rawan. Permukaan rawan sebenar pada sendi sinovia manusia akan berada dalam keadaan yang sama ada cembung atau cekung atau datang dalam saiz yang berbeza, ini boleh memberi kesan kepada ciri-ciri yang mempunyai ciri-ciri. Oleh itu, projek ini akan menggunakan ujian lekukan dan kaedah pengiraan perisian ABAQUS dalam menentukan tingkah laku biomekanik seperti tekanan liang dan hubungan tekanan rawan yang disebabkan oleh ketebalan yang berbeza rawan. Sebagai ketebalan perubahan tulang rawan, tekanan liang dan tekanan kenalan akan terjejas. Adalah dicadangkan bahawa kajian selanjutnya biomekanik rawan manusia dan aplikasinya akan mendapat manfaat daripada penubuhan teknik kejuruteraan sedia ada.

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**LIST OF SYMBOLS**

E – Young's Modulus

k – Permeability

$\nu$  – Poisson's ratio

r – Indenter radius

s – Second (time)

s – Second (time)

V- Voltage

R – Curved radius of specimen

## LIST OF ABBREVIATION

LVDT – Linear variable differential transformer

MRI – Magnetic resonance imaging

OA – Osteoarthritis

PBS – Phosphate Buffered Saline

## **CHAPTER 1**

### **INTRODCUTION**

#### **1.0 INTRODUCTION**

Osteoarthritis is the most common form of arthritis. Nearly one in two people may develop symptomatic knee osteoarthritis by age 85 years in United State of America. It causes pain, swelling, and reduced motion in human joints. It can occur in any joint in human body particularly hands, knees, hips, spine or knee. The main cause of the osteoarthritis is 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 principal function of cartilage is to provide a smooth, lubricated surface for articulation and distribute the load, minimize peak stresses on subchondral bone, and provide a friction-reducing, weight-bearing surface. Alterations associated with injuries, osteoarthritis, and other degenerative processes vary normal structure-function and affected the biomechanical properties of articular cartilage.



## **1.1 PROBLEM STATEMENT**

In previous studies, articular cartilage is usually study only based on a single thickness flat surface of cartilage specimen to the biomechanical behaviour. Therefore, this project will study on the different thickness of cartilage in indentation test in order to determine the biomechanical behaviours of cartilage.

## **1.2 OBJECTIVE**

The aim of this study is to investigate the geometrical effects of cartilage thickness on determining the biomechanical behaviours of articular cartilage.

## **1.3 SCOPE**

The scope of the project includes:

- To determine the thickness of cartilage specimen.
- To study the effects of cartilage thickness on biomechanical behaviours of cartilage in indentation test.

## CHAPTER 2

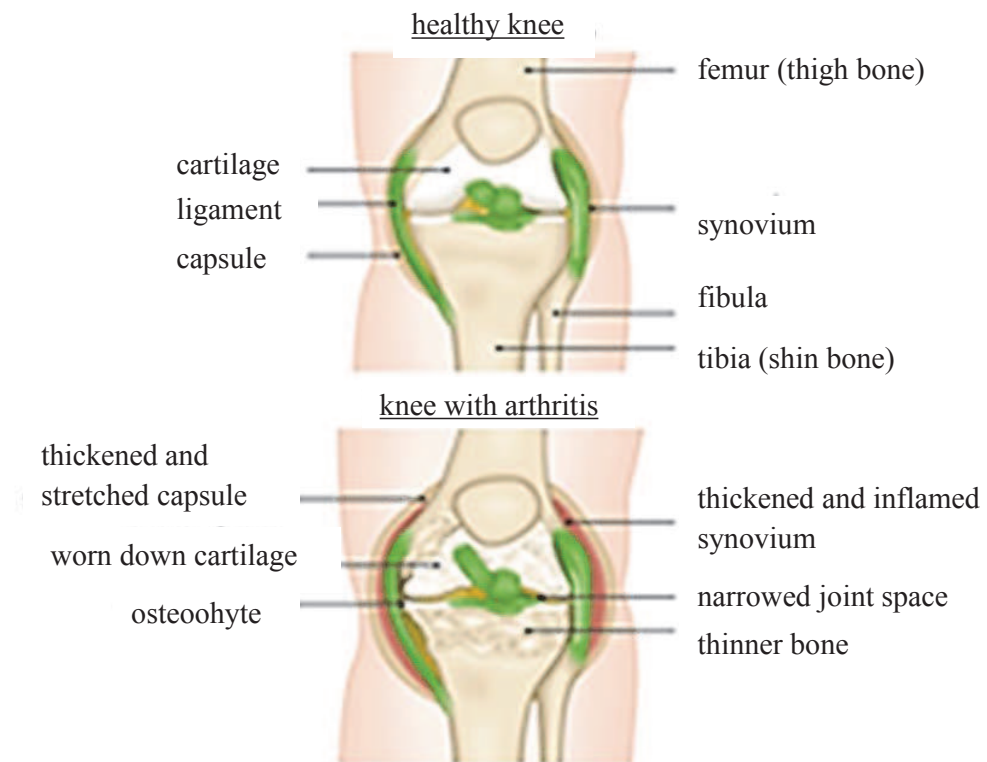
### LITERATURE REVIEW

#### 2.1 OSTEOARTHRITIS

Osteoarthritis (OA), is a syndrome of joint pain and dysfunction caused by the degeneration of joint, and it influence human the most compare to any other joint disease. It is a chronic condition due to the defect of cartilage. OA is one of the leading cause of disability and the main causes to this disability burden due to the hips or the knees. The commonness of OA is in the region of 10 to 20% of the adult population (Fransen, 2011).

There are more than one billion US dollars are spent every year on the surgery for joint disease in the United States, the majority of these are and mainly is caused by OA. Similarly the health and economic impact in other countries are as dramatic. The most common form of OA in Malaysia is knee OA. OA is strongly often caused by the aging of human body and the Asian are aging rapidly. Furthermore, OA are also caused by the heavy physical occupational activity, a required activity for many people living in rural area in the countries that are still developing (Fransen, 2011). The commonness of OA increases as the age increases and generally affects women more frequently compared to men. In fact, OA is the precipitating diagnosis for more than 90% of the increasing number of total hip or knee joint replacement operations being undertaken worldwide (Australian Orthopaedic Association, 2009).

Degeneration of articular cartilage caused by osteoarthritis is shown in Figure 2.1. It is one of the most common causes of pain and disability in the middle-aged group and senior citizen. OA affects all people no matter which ethnic groups, it also affects both gender no matter men and women, however OA occurs more frequently in women, (Buckwalter, 2000) and it is the most common cause of crucial disability in most populations of senior citizen. Lawrence et al have estimated that more than 20 million Americans have OA; the World Health Organization (WHO) estimates that one out of ten of the world's people over the age of 60 years suffer from OA, and that eight out of ten people with OA have limitation of movement and one quarter people will have difficulty in perform major daily activities (World Health Report Archives, 1995–2000). Moreover, every country in Asia are aging rapidly. It has been estimated that the percentage of people aged 65 years and over in Asia will increase more than double in the next two decades, where it increases from 6.8% in 2008 to 16.2% in 2040. In most of the developed world, demographic change was a slow process following by the steady socioeconomic growth over several era. In many Asian countries, these changes will be compressed into two or three era. (Kinsella, 2009). It was found that the commonness of either knee pain or knee OA is high, particularly given that the group are young which usually 15 years or above, with a average age of 30 to 39 years as shown in Table 2.1.



**Figure 2.1: Comparison between a healthy knee and knee with osteoarthritis.  
Adapted from Rebecca Canvin, Bupa Health Information Team (2012)**

**Table 2.1: Crude prevalence of knee pain or a diagnosis of knee osteoarthritis (OA). Retrieved from COPCORD Studies (2001)**

Asian region	Country/source (ref.)	Region/ethnicity	n.	Age (years)	Knee pain Male/female, %	Knee OA Male/female, %	
East	China/Shanghai <sup>17</sup>	Urban	5650	36-45	3/9	NA	
				46-55	7/17		
				56-65	14/26		
				66-75	14/24		
				> 75	9/17		
	China/Shantou <sup>23</sup>	Urban	2040	16-99	8	4	
	China/Taiyuan <sup>24</sup>	Urban	2188	35-39	9/18	3/4	
				40-44	(35-64 years)	3/9	
				45-49	7/16		
				50-54	10/27		
55-59				14/27			
60-64	13/34						
South	North Pakistan <sup>14</sup>	Rural	683	15+	NA	4	
		Urban poor	706			3	
		Urban affluent	608			5	
		All	1997			4/5	
	Bangladesh <sup>16</sup>	Rural	2601	15+	14	6/9	
		Urban poor	1307		14	10/8	
		Urban affluent	1252		16	6/16	
	India/Bhigwan <sup>11</sup>	Rural	4092	15+	10/16	4	
	India/Pune <sup>17</sup>	Urban	8145	15+	8	6	
	India/Jammu <sup>18</sup>	Mixed	1014	15+	NA	4	
	Pakistan/Karachi <sup>15</sup>	Urban poor	2210	15+	3/8	NA	
				35-44	1/3		
				45-54	3/7		
				44-64	2/11		
				65+	5/9		
Urban affluent				2022	15+	4/9	NA
35-44				0/6			
45-54	0/10						
44-64	6/18						
65+	12/17						
South-east	Thailand/Nakomayok <sup>10</sup>	Rural	2455	15+	NA	6	
	Philippines/Manila <sup>15</sup>	Urban	3006	15+	1	NA	
	Philippines/Luzon <sup>19,22</sup>	Rural	950	15-44	2/3	3/3	
				45-64	11/12		
	Vietnam/Hanoi <sup>20</sup>	Urban	2119	65+	24/8		
				16+		3	
				16-34	< 1/1		
				35-54	5/4		
	55-64	22/22					
	65+	41/36					
Malaysia/Banting <sup>21</sup>	Semi-rural		15+				
	Malay	1267		9/11	2/3		
	Chinese	474		3/6	1/1		
Indian	853		8/13	3/6			

NA, not available.

### 2.1.1 Causes

Common risk factors for OA included aging, obesity, old joint injury, overuse of joint, and the cause by genetics. However, the degeneration of articular cartilage is not only caused by the result of aging and wear. It is also because of high force due to collision and torsional loads which will increase the percentage of the degeneration of normal joints. By the way, the person who have an unusual joint anatomy, unstable joint, disturbances of joint or muscle irritation, or insufficient muscle strength or endurance probably have a greater risk of degenerative joint disease (Buckwalter and Mankin, 1998). In human, intensive physical exercises will also cause osteoarthritis development (L'Hermette, 2006). Apart from aging, there is some proof mostly from North American or European groups stated that obesity or heavy occupational physical activity are the risk factors for symptomatic knee and hip OA (Jensen, 2008). Furthermore, obesity, which was the another major risk , may be less common, although it is increasing and likely to have a major effect on OA commonness in the future. In the early stage of OA, the water content of cartilage will increased and this compositional crisis has been shown to have deep biomechanical effects. The increase of water content greatly reduces the intrinsic Young modulus and increase the permeability of the collagen-proteoglycans solid matrix of cartilage. This shows that the changes of these material properties will have high effects on the method cartilage supports the loads which apply onto the surface and the mode in which the interstitial fluid flows. Theoretical prediction made based on the functional responses of cartilage by considering the increased hydration show that cartilage may no longer function as the near-frictionless and wear resistant bearing material of the joint. Thus a vicious cycle is set up which will caused further breakdown of the tissue, possibly by increases in both the friction and wear rates of the cartilage surfaces; and finally OA developed (Kwan, 1986).

### 2.1.2 Symptoms

The people that experience OA will first have a sense of unease when using the joint. It has been described as stiffness or gelling. There will also have the feeling of unstable and unsafe on walking which will cause pain. The degree and duration of pain change but the pain of OA will be even worse while the joint are being use. This pain may be only happen for a short period during waking hours or it may be occur throughout. OA are mostly occurs in the hands, knees and hips. Hand OA is commonly affected at the base of the thumb and the joints at the end of the fingers. As time passes, defected joint will become red, swollen and tender, especially when OA first arise. Slowly, for more than few years, joint will formed firm knob swellings at the side which named as Heberden's nodes. For hip OA, the pain is often occurs in the front of the groin, and sometimes around the thigh, buttock or even down to the knee. Hip OA will have effect on walking. In knee OA, the pain is often become more damage by frequently usage (Arthritis Foundation of Malaysia, 2010).

### 2.1.3 Diagnosis

Synovial joint are often being checked by using plain radiographs and the diagnose of the joint with clinical syndrome of OA requires the presence of long-range joint pain. The patients whose have OA will have difficulty of movement, crepitus with motion and joint discharge. The most severely affected patients will develop joint deformation and subluxations. Patients with OA usually seek for medical attention due to the pain of joint and the pain they experienced are often be described as a deep aching poorly localized discomfort which has affecting for years. The pain may vary with the changing of weather, the pain will be harder when storms occurs or there is a drop in temperature, and the pain will also vary according to the activity taken. Activity that will cause pain are often begins simultaneously or after a short period of time when the joint is being use and may persist for hours after end of activity. Some people will find out the symptoms of degenerative joint disease following a small joint injury or strenuous physical activity, although the study of their radiographs indicated that the changes are consistent. In the further stages of the

OA the pain will be constant and may cause patients awake from sleep. As joint degeneration progresses go on, patients may notice that they have loss motion slowly and feel crepitus, or grating, catching and grinding sensations in the joint with motion. Joint enlargement due to osteophyte formation, joint subluxation and deformity occur later in the course of the disease.

The first signs of osteoarthritis include a decrease in the freedom of active joint movement. Physicians frequently diagnose osteoarthritis based on the patient's history and physical findings. Imaging studies other than plain radiographs, including bone scans, CT scans and MRI, and arthroscopic examination of joint surfaces, may be helpful in evaluation of early stages of degenerative joint disease, but they rarely are necessary for establishing the diagnosis (Buckwalter, 2000).

#### **2.1.4 Treatment**

There is no cure for osteoarthritis, but there are medications to help relieve pain. The doctor may recommend physical therapy (PT) or occupational therapy (OT) to help improve strength and function. Surgery may need to be conducted when a person was in severe pain when he moves. Doctors usually use painkillers to relief pain. The ideal painkiller such paracetamol is one of the painkillers that provides pain relief with minimal side effects. Beside this, pain can also be relieved by using other agents such as non-steroidal anti-inflammatory drugs (NSAIDs). However, these agents may cause bad effects as it may cause stomach irritation or ulcer. One of the common adverse effects of NSAIDs is it may cause stomach irritation or stomach ulcer. It is still preferable that pain relieving medication in OA be used "as and when required" rather than constantly. It is a smart move to lessen the mechanical burden on the joint when a person had OA. Weight reduction is the key to lessen the burden of OA if the patient is overweight. Muscle strengthening (quadriceps strengthening) is vital to stop the progression of knee OA. The patient is always advised to get information tips on how to carry out muscle exercises and knee protection aids. It is