Faculty of Manufacturing Engineering

DESIGN OPTIMIZATION OF SPRING LOADED KNEE BRACE FOR KNEE ARTHRITIS USING FINITE ELEMENT ANALYSIS

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Master of Manufacturing Engineering (Industrial Engineering)

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DESIGN OPTIMIZATION OF SPRING LOADED KNEE BRACE FOR KNEE ARTHRITIS USING FINITE ELEMENT ANALYSIS

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DECLARATION

I declare that this thesis entitles “Design Optimization of Spring Loaded Knee Brace for Knee Arthritis Using Finite Element Analysis” is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature: **…….**

Name: Siti Naimah Solehah Binti Mohd Idris

Date: 1 Feb 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Manufacturing Engineering (Industrial Engineering).

Signature: .....

Supervisor Name: Dr Zulkeflee bin Abdullah

Date: 1 Feb 2021

DEDICATION

To my beloved parents, Mohd Idris Bin Mohd Isa and Norrizan Binti Mahmud, the strong and gentle soul who always be there for me when I was down, taught me to never stop believing in Allah's plan and showering me with unconditional love, guidance and support.

To my siblings and friends, who are great to be around, who never stop encouraging me and give me the strength.

ABSTRACT

Osteoarthritis (OA) is the most common cause of knee arthritis in people. It also affects the physical functioning of the person. According to the 2010 Global Burden of Disease Study, an estimated 251 million people worldwide are living with OA knees. In many people, this is a major cause of work loss and severe disability. Individuals of all ages, genders, and races can and may have arthritis. The non-invasive treatment options are becoming more prevalent in the treatment of this medical symptom, and the use of knee braces is one alternative. Many studies have shown a reduction in pain and improved gait efficiency due to brace stabilization. Nevertheless, there is still a shortage of biomechanical studies to establish how a brace functions to alleviate pain. While knee braces are both practical and secure, their current designs are not widely used due to their bulkiness, which causes discomfort and difficulties for the wearer during extended periods of use. Since most Malaysians are suffering from osteoarthritis, this research will concentrate on knee support devices to prevent the development of osteoarthritis in Malaysia. The goal of this research is to optimize existing knee support devices and to evaluate the efficacy of improved design by using an optimization tool which is a SOLIDWORKS Simulation-Finite Element Analysis. Specifically, lightweight and portable knee braces will be designed to improve comfort, reduce knee pain and enhance the mobility of injured knees in daily life and sports activities. The quantitative method will be implemented in this study. The samples of this study were selected using a purposive sampling technique among Malaysian. Several people will be chosen to be respondents in this study according to their gender, age, ethnicity and profession. The information that received from the respondent is to understand what consumer need with knee support devices. So it can help in developing a product that fits the requirements of the users. The comparison of finite element analysis of improved design with the current spring-loaded knee brace is made, it is to compare the peak stresses that obtained when applying a certain force while performing physical activities. The stress on the knee brace gives a clear indication that knee brace is effective in shielding stress from the knee. This is because the stress is reduced from 58.67 MPa to 41.57 MPa. Therefore, the improved design offers a lightweight and compact knee brace to protect the knee from stress by increasing comfort, reducing pain in the knee, and enhancing injured knee mobility in daily life or sports activities.

ABSTRAK

Osteoarthritis (OA) merupakan yang paling utama penyebab kepada arthritis lutut dikalangan masyarakat. Ia juga mempengaruhi fungsi fizikal seseorang. Menurut Kajian Beban Penyakit Global 2010, dianggarkan 251 juta orang di seluruh dunia hidup dengan masalah lutut OA. Penyakit ini adalah penyebab utama kehilangan kerja dan kecacatan teruk. Individu dari semua peringkat umur, jantina, dan bangsa boleh dan mungkin menghidap radang sendi. Pilihan rawatan bukan invasif menjadi semakin lazim dalam rawatan gejala perubatan ini, dan penggunaan pendakap lutut adalah salah satu alternatif. Banyak kajian menunjukkan penurunan kesakitan dan peningkatan kecekapan berjalan kerana penstabilan pendakap. Walaupun begitu, masih ada kekurangan kajian biomekanik untuk menentukan bagaimana pendakap berfungsi untuk mengurangkan kesakitan. Walaupun pendakap lutut praktikal dan selamat, reka bentuknya sekarang tidak banyak digunakan kerana kekemasannya, yang menyebabkan ketidakselesaan dan kesukaran bagi pemakai untuk jangka masa penggunaan yang lama. Oleh kerana kebanyakan rakyat Malaysia menderita osteoartritis, penyelidikan ini akan menumpukan perhatian pada alat sokongan lutut untuk mencegah perkembangan osteoartritis di Malaysia. Matlamat penyelidikan ini adalah untuk mengoptimumkan alat sokongan lutut yang ada dan menilai keberkesanan reka bentuk yang lebih baik dengan menggunakan alat pengoptimuman seperti pendekatan elemen hingga. Secara khusus, pendakap lutut ringan dan mudah alih akan dirancang untuk meningkatkan keselesaan, mengurangkan sakit lutut dan meningkatkan pergerakan lutut yang cedera dalam kehidupan seharian dan aktiviti sukan. Kaedah kuantitatif akan dilaksanakan dalam kajian ini. Sampel kajian ini dipilih menggunakan teknik persampelan bertujuan di kalangan rakyat Malaysia. Beberapa orang akan dipilih untuk menjadi responden dalam kajian ini mengikut jantina, umur, etnik dan profesion mereka. Maklumat yang diterima daripada responden adalah untuk memahami apa yang sebenarnya diperlukan oleh pengguna dengan alat sokongan lutut. Oleh itu, ia dapat membantu dalam mengembangkan produk yang memenuhi kehendak pengguna. Perbandingan analisis elemen terhingga bagi reka bentuk yang lebih baik dengan pendakap lutut yang dimuatkan dengan pegas telah dijalankan, ini adalah untuk membandingkan tekanan puncak yang diperoleh ketika menerapkan daya tertentu semasa melakukan aktiviti fizikal. Tekanan pada pendakap lutut memberi petunjuk yang jelas bahawa pendakap lutut berkesan untuk melindungi lutut daripada tekanan. Ini kerana tekanan dapat dikurangkan dari 58.67 MPa menjadi 41.57 MPa. Oleh itu, reka bentuk yang lebih baik menawarkan pendakap lutut yang ringan dan padat untuk melindungi lutut dari tekanan dengan meningkatkan keselesaan, mengurangkan kesakitan di lutut, dan meningkatkan mobiliti lutut yang cedera dalam kehidupan seharian atau aktiviti sukan.

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In the name of Allah, the Most Gracious and the Most Merciful. All prise gives towards Allah SWT because of Him, I can complete my master project.

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F	-	Force matrix
K	-	Stiffness matrix
U	-	Displacement matrix
K_{eq}	-	Equivalent stiffness matrix
A	-	Cross-sectional area
L	-	Length
E	-	Young's modulus of elasticity
K^{-1}	-	The inverse of the stiffness matrix
ε	-	Strain
σ	-	Von Mises Stress
F	-	Force applied
m	-	Body mass
a	-	The acceleration of gravity

CHAPTER 1

INTRODUCTION

1.1 Background

The knee is the largest and one of the most easily damaged joints in the human body. And it is one of the important joints for daily movements. It consists of tendons, femur, cartilage, ligaments, meniscus, fibula and tibia as shown in Figure 1.1. Serious damage or injury to the ligament may cause major pain to people. Arthritis of the knee is frequently underreported, undervalued, and undertreated (Mat *et al.*, 2019). The disease trends affecting the population of the world are changing quickly from communicable to non-communicable diseases, arthritis of the knee is being classified as a non-communicable disease (Duarte *et al.*, 2017).

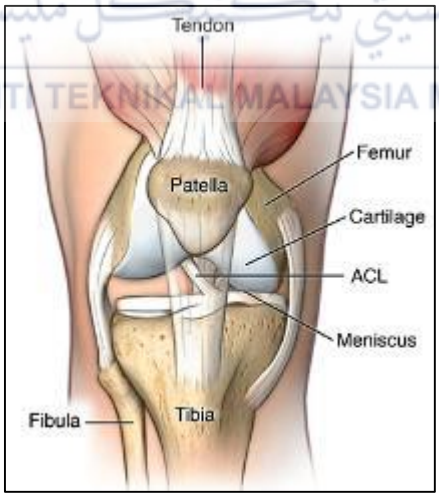

Figure 1.1: Parts of Knee (Johns Hopkins Medicine, 2020).

Individuals of all ages, genders, and races can and may have arthritis. Wellness Research Center at the University of Malaya reported that the approximate commonness of knee pain amongst adults 50 years of age and older living in Malaysia was 30.8%. In

contrast, in the past year, the prevalence of self-reported symptoms of knee arthritis was 25.4%. In Malaysia, the incidence of knee pain was reported at 45.6% of ethnic Malay relative to most other ethnic groups. In particular, the symptoms of knee pain and knee arthritis were associated with women, level of education, profession, dissociative disorders, and overweight (Mat *et al.*, 2019).

Swelling, stiffness, discomfort and reduced range of movement are common symptoms of joint arthritis. Symptoms or sign can come and go. There are four stages of knee arthritis: minor, mild, moderate, or severe. Serious arthritis can lead to extreme pain, diminished ability to participate in daily activities and difficulties in walking and climbing stair. Osteoarthritis, rheumatoid arthritis, and post-traumatic arthritis are the most severe cause of knee arthritis (Arthritis Foundation, 2018).

The non-invasive procedure is more prevalent to treat these diseases, and one of the alternatives is the use of knee braces. Some research demonstrated a decrease in discomfort and increased flexibility of the gait due to brace stabilisation. However, biomechanical science remains incomplete to establish how a knee brace works toward alleviate symptom (Lee *et al.*, 2016). The knee braces generally support, stabilize, or strengthen the knee. Its functions lengthen to the correction or prevention of deformities and improve function and delay disease progression (Chew *et al.*, 2007).

There are different forms of knee support devices used for knee pain and classified into several categories. Four types of knee brace commonly used are functional knee brace (FKB), unloader knee brace, patellofemoral knee brace, and, prophylactic knee brace (Toby Kinney and Wetherbee, 2013). Some of the knee braces on the market are less considered in terms of benefits. Research of knee support devices for an individual that has knee arthritis are narrow, and the results vary. Several users see no interest and also complained about fit, slippage, and discomfort of a knee brace (Segal, 2012).

Knee brace functions as an extra layer covering and creating a proper fit around the joint of the knee. Typically, the interface consists of elastic layer material. During the design cycle, the additional physical load such as comfort, bulkiness, extra weight, and fit must be taken into account. Figure 1.2 summarizes selected examples of knee orthoses according to their physical burden and performance (Jia, 2017).

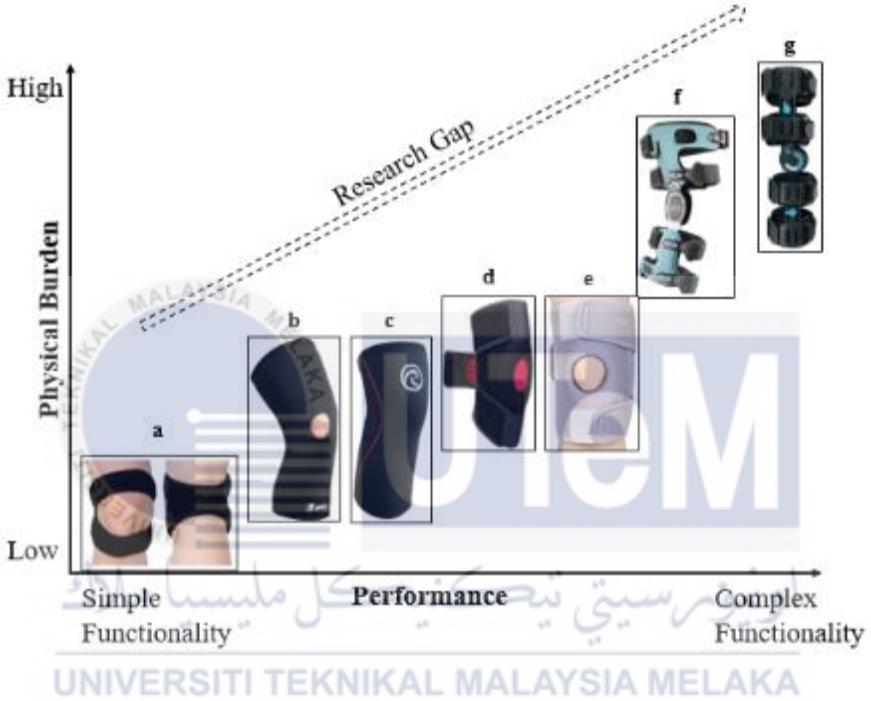

Figure 1.2: Existing Knee Orthosis

a) Neoprene Knee Support Patella Straps ST-NK031-1 (Smart Star International Development Ltd., n.d.)
b) Neoprene Knee Support Sleeve (Amazon.com, n.d.)
c) Rehband Rx 7mm Knee Sleeve (Rehband, n.d.)
d) Neoprene Compression Knee Support ST-NK035-1 (Amazon.com, n.d.)
e) Neoprene Compression Knee Support ST-NK035 (Amazon.com, n.d.)
f) OA Unloader (Podesta and Sherman, 2015)
g) Hinged Post Op Knee Brace (Amazon.com, n.d.)

Throughout this analysis, the SOLIDWORKS Simulation-Finite Element Analysis would be used as an optimization tool for the design improvement of knee support devices. This numerical simulation approach is used in many engineering and research fields and enables the behaviour of mechanical, thermal, or other complex structures to be modelled efficiently and accurately (Berk, 2009).

1.2 Statement of the Purpose

The purpose of this research is to improve the design of the spring-loaded knee brace and analyze the effectiveness of the improved design by using the optimization tool such as a SOLIDWORKS Simulation-Finite Element Analysis. The device will aid patients that have a problem with arthritis of the knee by providing comfort and pain relief. Identifying and analyzing the existing unloader knee brace in the market for knee osteoarthritis. Design a spring-loaded knee brace hinge on the back leg, that could boost the physical burden issues for current braces. Evaluate the effectiveness of the improvement of spring-loaded knee brace using finite element analysis.

1.3 Problem statement

Osteoarthritis (OA) is the highest cause of knee arthritis among people. It also affects individual physical functioning**.** According to the Global Burden of Disease 2010 Study, an estimated 251 million people are living with knee OA globally. An alternative to treating osteoarthritis includes utilizing knee braces. Evidence for the effects of bracing in patients with osteoarthritis in the knee is also inconclusive. The published Cochrane review, which involved 13 research (4 examining unloading knee braces), reported that there is still incompletes evidence of the knee bracing effectiveness, primarily due to bias challenging the findings from most of the studies (Thoumie *et al.*, 2018).

While knee braces are both practical and secure, their current designs are not widely used due to their bulkiness, which causes discomfort and difficulties for the wearer during extended periods of use. It consists of a frame made of hard materials (e.g. metal, plastics), fastened to the knee, and fastened to the leg by braces which are often too heavy for older people (mainly women) to wear comfortably for long periods (Stamenović *et al.*, 2008a).

The failure of the knee brace, it was related to obesity and a bad fit of the brace. Consumer enforcement and high costs have been described as issues with knee braces. These are problematic to wear for long times because of their size and the amount of force provided to the limbs to change alignment (Iorio and Healy, 2003). Some people see no interest and also complained about fit, slippage, and discomfort of the knee braces. A knee brace may feel heavy and bulky. Then poor fit may result in slipping. This problem will cause the patient condition to get worse and does not reduce the pain.

It was reported to be around 57% of patients thought that they are at risk of re-injury when wearing knee braces. Patients also complained of scratched, brace slipping, soreness, and tended to experience signs of knee unbalance when wearing a knee brace (Rankin, 1997). Most of the knee brace or knee orthotics available in the markets, whether for assistive or rehabilitative uses are costly (Goldner, Marcucci, and Schueler, 2019).

1.4 Objectives

This study provides a new design of knee support devices to help people that have knee arthritis (such as osteoarthritis) using a SOLIDWORKS Simulation-Finite Element Analysis as an optimization tool. Specifically, a powered lightweight and portable knee braces will be designed, which improves the comfortability, reduce knee pain, and enhances the mobility of injured knee in daily life and sports activities.

The specific objectives of this study are list as follows:

1. To identify and analyse the design and material of the existing unloader knee brace in the market for knee osteoarthritis;
2. To design a spring-loaded knee brace, that could improve the physical burden issues for current braces;
3. To analyse the design and material of the improvement of spring-loaded knee brace using SOLIDWORKS Simulation-Finite Element Analysis.

1.5 Scopes

This study will be focused on the design improvement of a knee support device, which problems related to knee arthritis usually faced by a senior citizen and those engaged in physical activity in Malaysia. For the type knee arthritis, will be focused on Osteoarthritis and the treatments only focused on mild stages of OA with used of knee support devices. The spring-loaded knee brace will be focused on in this study to be improved. This study primarily focused on the mechanical analysis of knee orthoses such as strength, material, and endurance. This knee brace is designed to function as a support device, not a rehabilitative one.

1.6 Significance of the Study

Knee pain is generally affected by most people and can be due to degenerative conditions, trauma and sports injuries. Using appropriate knee support devices can help recover from injury and avoid further damage. Scientifically developed knee braces are intended to re-align the knee joint by reducing pressure on the affected area. They also reduce the associated discomfort by avoiding further joint wear and tear. The device will aid patients that have a problem with arthritis of the knee by providing comfort and pain relief. The main

targets of this research are individuals with ageing-related knee pain, and an individual with a knee injury during sport, or physical activity that is wishing to avoid the potential of cartilage eroded.

1.7 Project schedule/Gantt chart

Table 2.1: Gantt chart of the project

No.	Activities	Month					
		Mac April	May June	July August	Sep Oct	Nov Dis	Jan Feb
1	Meet supervisor						
2	Define problem and objectives						
3	Literature review						
4	Data collection						
5	Data analysis						
6	Interim report writing						
7	Submission progress report I & II						
8	Design and implementation						
9	simulation						
10	Result analysis						
11	Concluding						
12	Submission progress report III & report of MP II						
13	Presentation						

1.8 Chapter Summary

The first chapter of this research starts with the background of the study and further describes the use of knee support devices as one of the alternatives to treat knee arthritis and types of knee support devices that commonly used in Malaysia. This is followed by the problem statement, research objectives, scopes and significance of the study. The chapter concludes with the project schedule or Gantt chart of the project.

CHAPTER 2

LITERATURE REVIEW

Research needs to be carried out very well to achieve the quality of these preventive care devices. The research question will be focused on in this chapter. The research question will guide the literature search and analysis of the data. The following research question will be answered in the literature review to guide the writing of the data: What is the structure of the human knee, and how does our society often have issues with the knee? What are the common disease associated with a knee problem, and how can it be treated in preventing the disease? What types of knee support devices available in the market and does it work? Does the knee brace recognize market demand, and how to validate the design of the knee brace?

2.1 Knee anatomy

In developing knee braces, the understanding of the knee structure is important, this is because it will facilitate to design of the knee braces. The knee joint performs an important role in the transmission, absorption, and redistribution of body weights and strengths. The knee is the body's strongest joint. It takes almost normal knee function to perform the daily routine activities. Knowledge of knee anatomy is critical when gaining an understanding of an injury and whether the condition can be healed or fixed. Diego Costa Astur et. al state in their journal, the knee created by the lower end of the thigh bone (femur) moving at the upper end of the shin bone (tibia) and the knee cap (patella) slipping in the groove at the end of the femur. To ensure stability large ligaments are attached to the femur and tibia. Long thigh muscles provide strength to the knee joints (Astur *et al.*, 2011).

Jawad E. Abulhasan and Micheal J. Grey also reported in their journal that the knee is a hinge joint that complicated altered with the widest flexion and extension motion on the vertical plane known as a sagittal plane, as well as valgus and varus rotation on the frontal axis. It also enables the medial rotation at the end of the flexion of the knee and the lateral rotation at the terminal extension of the knee both at the horizontal plane. It consists of two bone joints (Figure 2.1); the articulation between the *femur* and the *tibia* carries most of the body weight, while the articulation between the patella and the femur enables the forces generated by the contraction of the femoris quadriceps over the knee to pass frictionlessly. The knee consists of two major joints (Figure 2.2): the *tibiofemoral joint* and the *patellofemoral joint*, enable the knee to function on three-planes of motion in Figure 2.3. The position of the knee between the femur and tibia, and its muscle mass-bearing function cause it is prone to injury (Abulhasan and Grey, 2017).

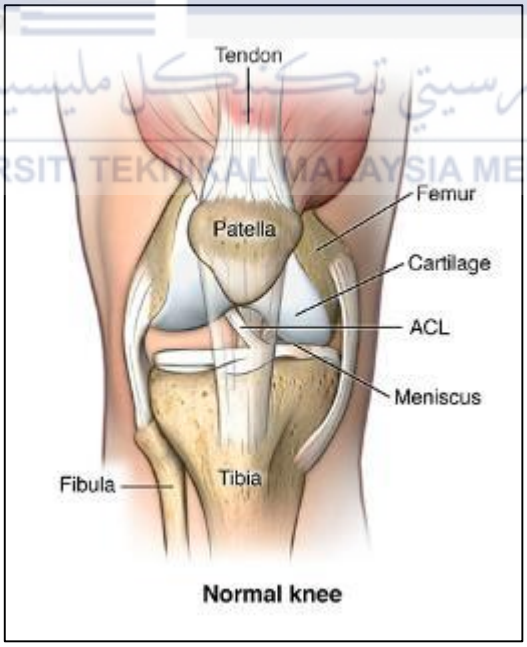

Figure 2.1: Two Bone Knee Joints Tibia and Femur (Johns Hopkins Medicine, 2020)