ASSISTIVE KNEE JOINT DEVICE FOR OVERWEIGHT PERSON

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science in Mechatronics Engineering

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ABSTRACT

This research presents a light weight assistive knee joint device for overweight persons. Overweight persons (BMI between 25-30 kg/m^2) experience 2.9-4.7 times the bodyweight load at the knee joint during walking, as such their knee joints are exposed to the danger of crushing. To lead healthy normal life, overweight persons need to reduce body weight. Overweight people need to walk for a longer duration to have more metabolic activity so that more calories are burnt to reduce body weight. So far such devices have not been researched to help the overweight people reduce their body weight through walking for a longer duration without damaging their knee joints. Research has shown that two main muscles which are the Vastii medial muscle and Gastrocnemius muscle contribute the most to the knee joint during walking. Thus overweight peoples require knee support systems which will reduce stresses at the knee joints as well as minimize muscle activations around the knee joint to help them walk for a longer time safely. A light weight exoskeleton consisting of a compression spring, a standard universal joint, a screw jack based mechanism, and straps for attaching the device with the thigh and the leg is developed to reduce the load at the knee joint. The screw jack helps adjust the initial deflection of the compression spring to support a portion of the body weight and then transfers this weight to the leg. The research investigated the effectiveness of this exoskeleton compared to the knee band by conducting experiment with a compression spring set to 2.5 cm deflection. The results show that both the knee band and exoskeleton reduces the Gastrocnemius muscle activity significantly. The average muscle reduction for the knee band was 66.32 % while for the exoskeleton prototype it was 63.32% with respect to the maximum muscle excitation during reference phase. The knee band reduces Gastrocnemius muscle activity more than the proposed exoskeleton. Due to the compression of the spring, 16.8 kg force load has been reduced at the knee joint. Though the muscle activation reduction is higher when using knee band, the range of load reduction cannot be adjusted as in the developed assistive knee joint since it is unable to sustain any compressive load. The higher muscle activation of the assistive device may be due to the straps arrangements and shape. It is expected that further research would help to improve the performance of this device.

ملخص البحث

يعرض هذا البحث جهاز مفصل الركبة المساند للأشخاص ذوي الوزن الزائد. تتعرّض ركب أصحاب الوزن الزائد (مؤشر كتلة الجسم ما بين 30-25 كجم/ م^{٢})، لحمل وزن جسم ما بين ٢,٩ الى ٤,٩ ضعف ما تتعرّض له ركبة غيره أثناء المشي مما يعرضها لخطر التهشم.لعيش حياة طبيعية، يحتاج صاحب الوزن الزائد الى تخفيف وزنه عن طريق رياضة المشي. حيث يساعد المشي لأوقات طويلة عملبة الأيض وبالتالي حرق مزيدا من السعرات الحرارية وما يتبعه من تخفيف للوزن.هناك فراغ في البحث العلمي في مجال أجهزة مفصل الركبة المساندة بالرغم من أثرها الكبير في مساعدة ذوي الوزن الزائد على تخفيف أوزانهم عن طريق المشي لأوقات طويلة من دون الاضرار بركبهم.أظهرت الأبحاث أن عضلات كلا من الفخذ و الساق تسهمان بشكل كبير في الضغط على مفصل الركبة حال المشي. لذلك فان ذوي الوزن الزائد بحاجة الى أجهزة دعم للركبة تعمل على تقليل الضغط على هذا المفصل وكذا تقليل نشاط العضلات حوله ليتمكنوا من المشي لمسافات طويلة بأمان.جهاز مفصل الركبة المساند المقترح في هذا البحث عبارة عن هيكل خارجي خفيف الوزن يحتوي على نابض ضغط Compression Spring، مفصل قياسي Standard Universal Joint، رافعة لولبية Screw- based Mechanism، وأخيرا مجموعة من الأشرطة الرابطة لربط الجهاز بالفخذ والساق. مهمة الرافعة اللولبية تعديل الانحراف الأولي لنابض الضغط لدعم جزء من وزن الجسم، وبعد ذلك تقوم بنقل هذا الوزن الى الساق. تمّ اعتماد رباط الركبة Knee Band كأساس مرجعي لمقارنة فعالية الجهاز المقترح في هذا البحث، كما تمّ ضبط نابض الضغط على انحراف ٢,٥ سم. أظهرت النتائج أن كلا من رباط الركبة والجهاز المقترح هنا يقومان بتقليل نشاط عضلات الساق بصورة كبيرة وصلت الى ٦٦,٣٢% بالنسبة لرباط الركبة و ٦٣,٣٢% للمفصل المساعد المقترح وذلك مقارنة بمعدّل اثارة العضلات الأقصى خلال الفترة المرجعية. كما أنه بسبب نابض الضغط في الجهاز المقترح، تمّ تقليل الحمل على الركبة بمقدار ١٦,٨ كجم.بالرغم من أن رباط الركبة قام بتقليل نشاط العضلات بصورة أكبر،الا ان مقدرته على تقليل الحمل عليها غير قابل للتعديل كما هو الحال في الجهاز المقترح. ربما يكون نشاط العضلات أكبر في الجهاز المقترح بسبب شكل وترتيب الأشرطة الرابطة، ومن المتوقع أن المزيد من البحث عليه سيساعد في تحسين أدائه.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Azizullah Saleem

Signature………………………. Date ………...................

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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Affirmed by Azizullah Saleem

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Signature	Date

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In the name of Allah the most gracious the most merciful

Alhamdulillah, all praise be to Allah SWT for helping me to complete my dissertation successfully. Next I would like to thank my supervisor Dr Md Raisuddin Khan and co supervisor Dr Shahrul Na'im Sidek for their help and support during my research work. Moreover I would like to thank the International Islamic University Malaysia and the Ministry of Higher Education (MOHE) for their financial support through research grants. Further I would like to thank all of my colleagues who helped me in one way or another through their expertise. Lastly I would like to thank my parents and siblings for their continuous love and support during this stage of my life.

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LIST OF SYMBOLS

d	Wire diameter of the spring
d_m	Mean diameter of the acme thread rod
D	Mean diameter of the spring
D_o	Outer diameter of the spring
f	Friction coefficient of the acme thread rod
F	Spring force
G	Material elastic modulus
k	Spring constant
l	Lead of the acme thread rod
L_{free}	Free length of the spring
n	Number of starts
n_a	Number of active coils
p	Thread pitch
T_L	Torque for lowering the load
T_R	Torque for rising the load
Δx	Spring deflection
α	Thread angle of the acme thread rod
Θ	Pitch angle of the spring

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Around 2.1 billion people worldwide are either overweight or obese (Robert, 2014). Weight linked epidemic is not only limited to the developed countries because the number of persons suffering from obesity in the developing countries is also significant. About 115 million persons in developing countries have suffered from obesity during the last few decades. The upsurge of obesity is also an occurrence among the people in the Middle East, Pacific region and Asia. The overweight or obese population percentage of the above locations is about 20% as specified by researches from Japan. The pandemic of obesity is gripping the world as a whole (The Obesity Pandemic, 2005). In the next section some of the problems associated with obesity will be discussed.

1.2 OSTEOARTHRITIS OF THE KNEE JOINT

Makk (2007) has identified the areas of the joints and spine, as the location wherein the wear are mostly accelerated by obesity. The wear causes an increase in the osteoarthritis (OA) of the knee. Further research by Browning (2012) mentioned that the likely contribution to the progression or development of osteoarthritis is from the joint loads that are abnormal and larger which is normally experienced by obese persons.

In addition Lozano et al (2012) stated further that for each additional kilo of body mass, the risk of developing osteoarthritis was between 9-13% for the obese patients. However there is a 35% increase in the risk of developing osteoarthritis for a weight gain of each 5 kg. Browning and Kram (2007), mention that for large-joint osteoarthritis, reducing obesity is the main preventable risk factor.

In addition, Japanese individuals who were obese had lower leg strength relative to body weight compared to lean individuals shown in a study reported by Hulens, Vansant, Lysens, Claessens, and Muls, E. (2002). This is because there is an inverse relationship between physical activity and obesity. Moreover Nantel, Mathieu, and Prince, F. (2011) mentioned that obese individuals are at a higher risk of developing musculoskeletal pain because of the musculoskeletal system alterations effects during walking.

1.3 KNEE JOINT OPERATION

Knee joint operation possibility is increased as mention in the research by Hayashi (2009) that a joint replacement chances for an obese patient is increased substantially. A Body Mass Index (BMI) greater than 30 have 8 times higher knee replacement chances while for a BMI of 35 or more, the chances are 18 times higher. Furthermore a joint replacement surgery operation has shown that an average weight of 1.2 kg was gained by the patient after surgery.

The Table 1.1 shows the Body Mass Index (BMI) categories for obese person as classified by the World Health Organization.

Table 1.1 Classification of Obesity According to the World Health Organization (Lozano, Núñez, Sastreand and Popescu, 2012)

BMI	Category
25-29,99 kg/m^2	Overweight. Class 0
30-34,99 kg/m^2	Obesity. Class I
35-39.99 kg/m^2	Severe obesity Class II
>40 kg/m^2	Morbid obesity. Class III

Therefore, to reduce the chance of joint replacement surgery, the obese person needs to reduce his weight (Powell, Teichtahl, Wluka, and Cicuttini, 2004). Reducing weight can decrease the load on the knee as shown through experiment conducted based on 18-month clinical trial of exercise and diet by Messier, Gutekunst, Davis and DeVita (2005). They found that during daily activities, the load exerted on the knee per step resulted in a 4-fold reduction for each pound of the weight that will be lost.

Hence assistive knee joint device is proposed to meet the problems associated with obesity such as osteoarthritis, musculoskeletal pain and knee joint operation.

1.4 PROBLEM STATEMENT AND ITS SIGNIFICANCE

To lead a healthy normal life, an overweight person needs to reduce his/her body weight. Physical exercise is the best method of controlling body weight, specifically walking. Walking though is good for normal people, is not easy for overweight persons; since, during walking, the knee joints are subjected to the stresses equivalent to few times the body weight. As the body weight of an overweight person is already high, the excessive stresses that develop at the knee joint may lead to crushing of the knee joint. There are exoskeleton support devices reported in the literatures for normal people to help carry big amount of load with reduced metabolic activity so that they can carry the load for a duration few times the normal duration. However, the case of overweight people is different; they need to walk for a longer duration to have more metabolic activity so that more calories are burnt to reduce body weight. So far such devices have not been researched to help the overweight people reduce their body weight through walking for a longer duration without damaging their knee joints.

1.5 RESEARCH OBJECTIVES

Following are the objectives set for this research:

(1) To design an assistive device to minimize the stresses at the knee joints and the surrounding muscles of an overweight person during walking.

(2) To develop the prototype of the assistive knee joint device.

(3) To evaluate the performance of the proposed assistive knee joint device using EMG signal.

1.6 RESEARCH METHODOLOGY

(1) The research begins with a detailed literature review on the problems and solutions related to overweight persons.

(2) Design of a mechanism that will be able to help reduce stresses at the knee joint and muscle activation of the muscles around the knee joint.

(3) Fabrication of a prototype of the assistive knee joint device.

(4) Design of instrumentation for measuring change of muscle activation while wearing the assistive device.

(5) Performance evaluation of the assistive knee joint device through analysis of muscle data of different overweight individuals.

Figure 1.1 shows the flowchart of the research methodology.

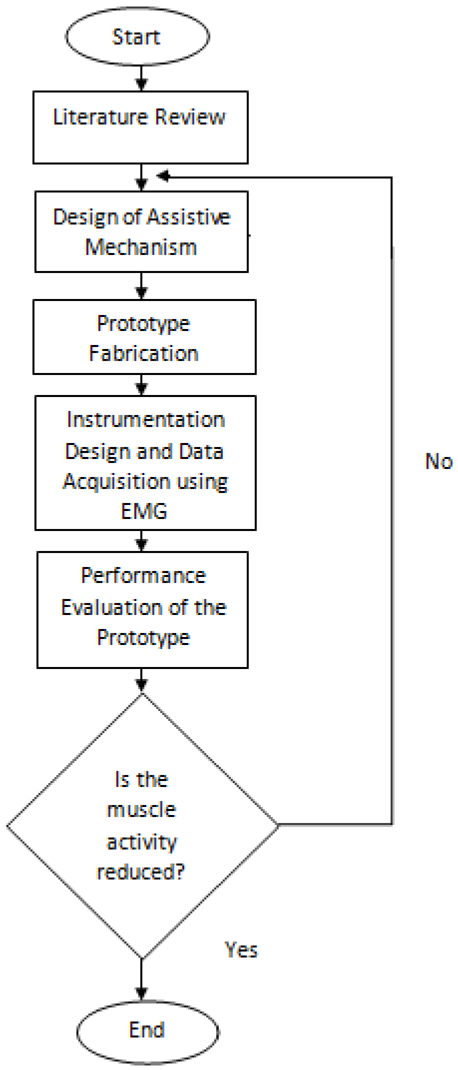

Figure 1.1 Research methodology flowchart

1.7 DISSERTATION ORGANISATION

This thesis is discussed as follows; Chapter one is an introduction to the research where an overview of the problems associated with overweight people is given. Alongside with the problem statement and its significance, objectives and research methodology are also presented here. Chapter two is a review of the related literature that offers the foundation for this work. Highlight is made on the state of art of different types of assistive knee devices currently available. Chapter three discusses the prototype development. Chapter four explains the experimental setup for the experiment. Chapter five shows the results achieved in the research. Chapter six summarise the assessment of the accomplished objectives in the conclusion and mention the recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the gait cycles, knee joint loading, and the leg muscles involved in the gait. Further reviews are presented on researches related to general assistive devices and problems such as rehabilitation for stroke, spinal cord injuries, and elderly and the existing solutions to their problems. The knee braces and their effect on the knee joint are also reviewed here. Finally the principal of the proposed exoskeleton is highlighted.

2.2 GAIT CYCLE

For a detail analysis of the gait, Cunado, Nixon and Carter (2002) described the cycle as shown in Figure 2.1. For the same foot, duration between successive instances of initial foot-to-floor contact (heel strike) is defined as the time interval of a gait cycle. There are two distinct periods for each leg. When the foot is in contact with the floor, it is called stance phase and when the foot is off the floor moving forward to the next step, it is called the swing phase. With the heel strike of one foot that starts the beginning of the gait cycle, it signals the beginning of the stance phase. The left foot is brought flat on the floor as it support the body weight as the ankle flexes. As the left heel lifts of the ground, the right leg swings through in front of the left leg. The supporting left knee flexes as the body weight moves onto the right foot. Then the left foot lifts of the ground ending the stance phase with toe-off. When the toes of the left foot leaves the ground, it marks the start of the swing phase. The left leg swings forward to strike the ground in front of the right leg as the weight is transferred onto the right leg. With the heel strike of the left foot, it marks the end of gait cycle. Between successive points of contact of the same foot, stride length is defined as the linear distance in the plane of progression. Distance between successive contact points of opposite feet defines the step length. The motion between successive heel strikes of opposite feet defines a step. Two steps makes up a complete gait cycle.

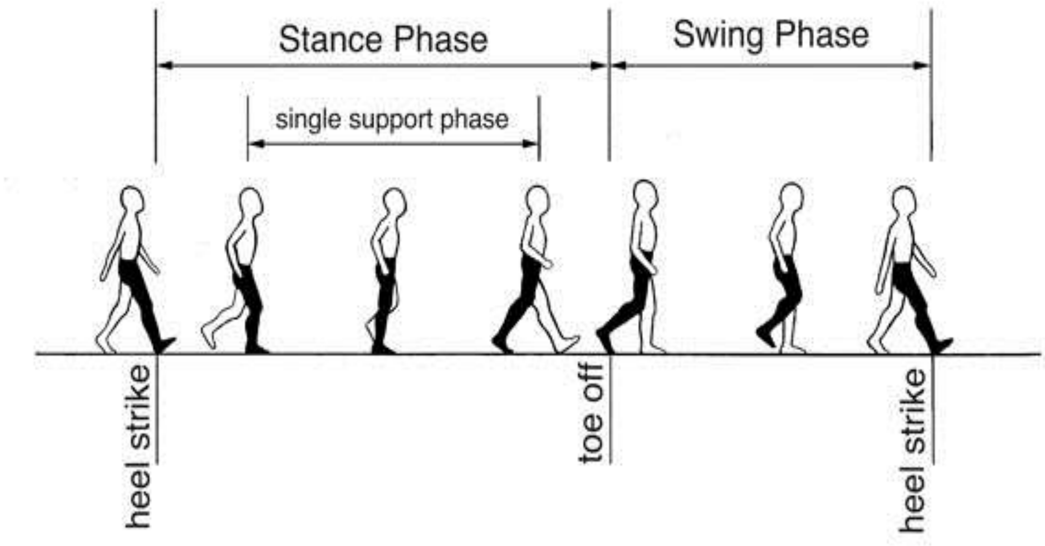

Figure 2.1 Gait Cycle (Harrington, 2005)

Compared to normal gait, the gait of overweight person is not much different. However the following changes were observed by Sheehan and Gormley (2013) while conducting experiment on 25 overweight and 25 non-overweight person. They found that the overweight person had higher maximum ground reaction force as they spend longer time in stance phase and there were variations in knee varus, knee flexion, and hip abduction and flexion

2.3 KNEE JOINT LOADING

Kyriacos and Johannah (2009) states that about 2.7-4.9 times bodyweight forces are experienced by the knee joint during walking at normal phase. Out of the total load at the knee joint, 45%-75% is carried by the knee meniscus as shown in Figure 2.2. Medial load of 50% is carried by the medial meniscus and the lateral load of almost 100% is carried by the lateral meniscus during full extension phase of walking.

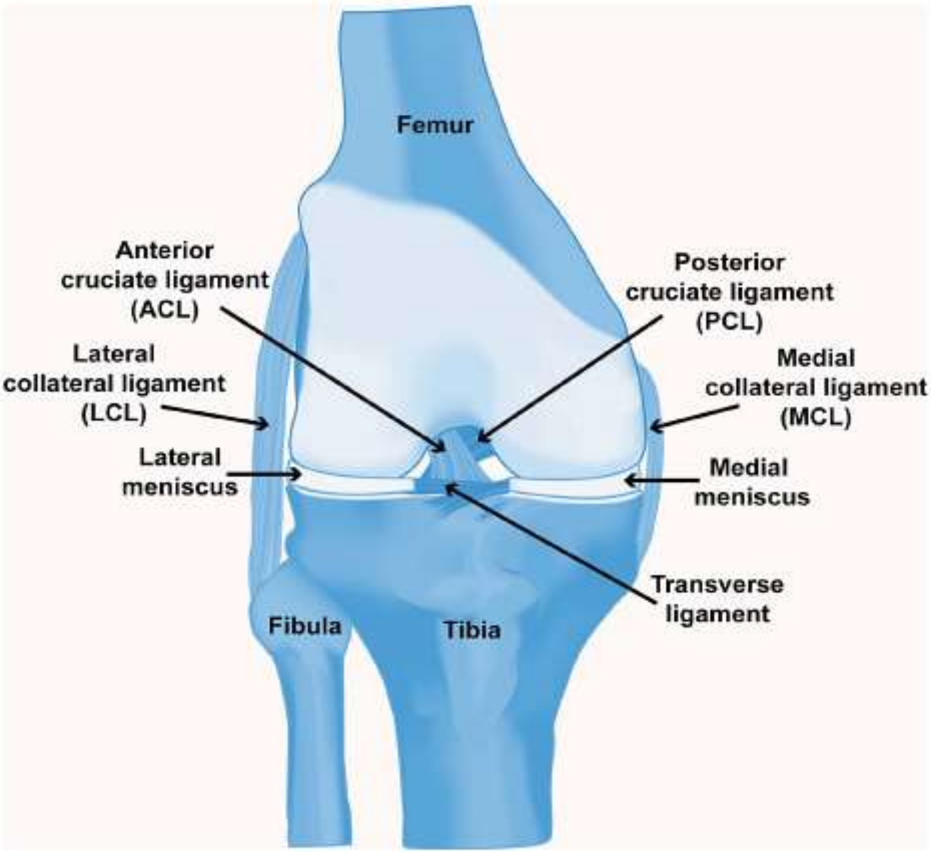

Figure 2.2 The Knee Meniscus (Kyriacos and Johannah, 2009)

The bar chart in Figure 2.3 shows the mean knee compressive forces for the BMI in the range of 27-29.9 (overweight), 30-34.9 (obese) and more than 35 (severe obesity and morbid obesity). (Mackenzie, 2011). The mean knee compressive forces increases with higher BMI.

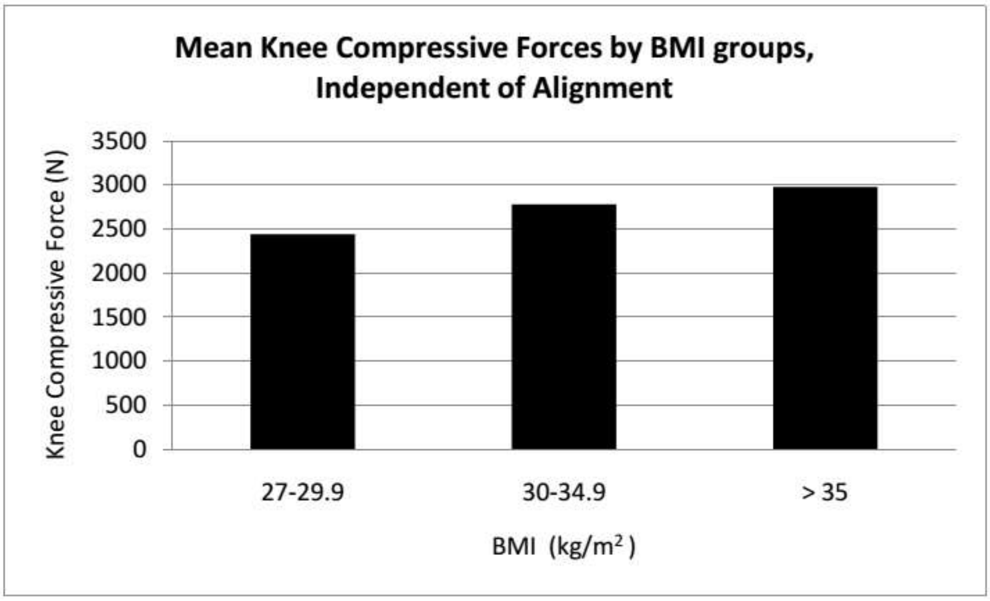

Figure 2.3 Knee compressive forces based on BMI (Mackenzie, 2011).

2.4 LEG MUSCLES INVOLVED IN THE GAIT CYCLE

As presented by Sasaki and Neptune (2010), Figure 2.4 shows contribution of leg muscles to the joint contact forces during stance and swing phase. The muscles involved are Vastii, Rectus Femoris, Gastrocnemius, Soleusfemoris, Hamstrings, Biceps Femoris Short Head, Gluteus Maximus and others. The highest forces occurs in the stance phase from the Vastii muscles and Gastrocnemius muscle at about 810 N and 860 N respectively. The high muscle contribution by the Vastii muscles and Gastrocnemius muscle is caused by the high load experienced by the knee joint during the stance phase of the gait (0-60%). The muscles of the leg are shown in the Figure 2.5(a) and (b).