FALLS AND GAIT CHARACTERISTICS
IN OLDER PEOPLE WITH KNEE OSTEOARTHRITIS

BY

MISS PRAEWPUN SAELEE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE (PHYSICAL THERAPY)
FACULTY OF ALLIED HEALTH SCIENCES
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2016

FALLS AND GAIT CHARACTERISTICS IN OLDER PEOPLE WITH KNEE OSTEOARTHRITIS

BY

MISS PRAEWPUN SAELEE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (PHYSICAL THERAPY)
FACULTY OF ALLIED HEALTH SCIENCES
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2016

THAMMASAT UNIVERSITY
FACULTY OF ALLIED HEALTH SCIENCES

THESIS

BY

MISS PRAEWPUN SAELEE

ENTITLED

FALLS AND GAIT CHARACTERISTICS IN OLDER PEOPLE WITH KNEE OSTEOARTHRITIS

was approved as partial fulfillment of the requirements for
the degree of Master of Science

on Approval date July 26, 2017

Chairman Pinailug Tantilipikorn Earde

(Assistant Professor Pinailug Tantilipikorn Earde , Ph.D)

Member and Advisor Plaiwan Suttanon

(Assistant Professor Plaiwan Suttanon , Ph.D)

Member and Co-advisor Pagamas P

(Pagamas Piriyaprasarth , Ph.D)

Member Sopa Pichaiyongwongdee

(Associate Professor Sopa Pichaiyongwongdee)

Dean

(Associate Professor Kampol Ruchwit , Ph.D)

Thesis Title	FALLS AND GAIT CHARACTERISTICS IN OLDER PEOPLE WITH KNEE OSTEOARTHRITIS
Author	Miss Praewpun Saelee
Degree	Master of Science
Major Field/Faculty/University	Physical Therapy Faculty of Allied Health Sciences Thammasat University
Thesis Advisor	Asst.Prof. Plaiwan Suttanon, Ph.D./PT.
Thesis Co-Advisor	Pagamas Piriyaprasarth, Ph.D./PT.
Academic Years	2016

ABSTRACT

The aim of this study was to compare gait characteristics between older people with and without knee osteoarthritis and to determine the correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis. A total of 48 healthy older people and older people with knee osteoarthritis participated in this study. The parameters in this study were spatiotemporal characteristics and angular displacements of hip, knee and ankle joints in the sagittal, coronal and horizontal planes at heel strike, midstance, toe off and mid swing. All participants were assessed with VICON™ motion system while walking at their self-selected speed.

In this study, there were significant differences in some parameters between groups. The velocity, cadence, step length, single support time, and stride length of the knee osteoarthritis group was less than the control group. Step time, stride time and double support time of the knee osteoarthritis group were significantly greater than the control group. Participants with knee osteoarthritis had greater knee flexion, varus, and external rotation during the initial contact phase. In mid stance, knee varus and external rotation and hip flexion of the knee osteoarthritis group were significantly greater than the control group.

In conclusion, participants with knee osteoarthritis adopt different compensatory biomechanical strategies while walking. There were significant differences in spatiotemporal and kinematics parameters among older people with mild to severe knee osteoarthritis. These could be detected through 3D gait analysis. Knee osteoarthritis influenced gait kinematics involving not only knee joint but also hip and ankle joint movement.

Keywords: gait, kinematics, spatiotemporal, osteoarthritis, falls

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation to my advisor, Assistant Professor Dr. Plaiwan Suttanon for her kindness supervision, invaluable suggestion, and encouragement throughout the study. Also, I am deepest appreciated to my Co-advisor, Dr. Pagamas Piriyaprasarth for her excellent advices, guidance and support. I am also deeply grateful to my committee members, Assistant Professor Dr. Pinailug Tantilipikorn Earde for her constructive comments and suggestions in this study. I express special thanks to Associate Professor Sopa Pichaiyongwongdee, who served as external examiner, for her valuable comments. Special thanks are extended to Miss Vinitha Pungthanom, the officer of the Sports Science and Sports Development Department at Faculty of Allied Health Sciences, Thammasat University for her assistance in preparing devices for data collection of this study. I wish to thank all participants who participated in this study.

Last but not least, I would like to express my gratitude to my father, mother and my sister for their support and warmth. They always let me choose my own way and encourage me.

Miss Praewpun Saelee

TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS

(Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Symbols/Abbreviations	Terms
ASIS	Anterior superior iliac spine
cm	Centimeter
cm/sec	Centimeter per second
kg	Kilogram
min	Minute
n	Number
OA	Osteoarthritis
%BW	Percent body weight
sec	Second
steps/min	Steps per minute
S.D.	Standard deviation
WOMAC	The Western Ontario and McMaster Universities Osteoarthritis
yr	year
2D	two dimensions
3D	three dimensions

CHAPTER 1
INTRODUCTION

This chapter provides background and rationale of gait characteristics in older people with knee osteoarthritis and discusses its importance in relation to falls. The purpose of this thesis will be outlined at the end of the chapter.

1.1 Background and rationale

By 2050, the number of world population ageing will be more than other age groups. The proportion of older population is expected to rise from 12 percent in 2015 to more than 16 percent in 2030 [3]. In Thailand, the number of older people who are aged 60 years or over will increase more than 20 percent over the next five years [4]. Growth in the numbers of older population will increase the demand of health care, financial and social support, as well as sufficient government support.

Falls are one of the leading causes of serious injury and hospital admissions in older people [5, 6]. Falls have been reported as one of the major public health issues. One in three of people age 65 and above falls annually [7]. Arthritis has been reported to be one of the factors that raise the probability of a fall for over 25 years [8, 9]. Due to the fact that osteoarthritis has been reported as the most prevalent form of arthritis [10]. Osteoarthritis has been reported as risk factor for falls in ageing people [7]. Most of people with knee osteoarthritis had a 30% more chance of experiencing a fall compared to people who did not have knee osteoarthritis [11].

Most of the incidences of falls occurs during walking [12]. Moreover, previous studies have reported correlation between gait characteristics and fall risk in ageing people [12, 13]. Increased risk of falls has been correlated with shorter stride length [11, 14], increased double support time, and slower gait speed compared with healthy aging group [11, 14, 15, 16]. Older people with knee osteoarthritis may adopt different biomechanical compensatory strategies while walking. A reduction in knee joint movement due to muscle weakness, pain or deformity that may result from worsening knee osteoarthritis, leading to higher deficits in balance control [17]. Gait biomechanics may differ between people with and without knee osteoarthritis. People with knee osteoarthritis have greater variations in step width, step length and double support time compared with healthy aging group resulting in the reduction of gait control [18]. However, there is still limiting information regarding the changes in gait in people with knee osteoarthritis in particular how these changes could be related to falls risk in older people with knee osteoarthritis. Overall, the point relationship between the biomechanics of gait and falls in older people with knee osteoarthritis represents potentially important of clinical research area in which could lead to appropriate falls prevention intervention strategies specifically, for this group of people

1.2 Research questions

1.2.1 Are there any differences in gait characteristics between older people with and without knee osteoarthritis?

1.2.2 Is there any correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis?

1.3 Purposes of the study

1.3.1 To compare gait characteristics between older people with and without knee osteoarthritis.

1.3.2 To determine the correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis.

1.4 Hypotheses

1.4.1 There would be significant differences in gait characteristics between older people with and without knee osteoarthritis.

1.4.2 There would be significant correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis.

1.5 Benefits of the study

1.5.1 The results would provide the information of differences of the gait characteristics between older people with and without knee osteoarthritis that might be beneficial for further developing intervention strategies for older people with knee osteoarthritis.

1.5.2 The results would provide the information on the level of correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis.

CHAPTER 2
LITERATURE REVIEW

This chapter introduces the definitions, prevalence, pathologies of knee osteoarthritis, defines falls, and describes the risks of falling in older people with knee osteoarthritis. The chapter also reviews previous research findings of gait characteristics in older people with osteoarthritis, especially when associated with falls.

2.1 Ageing population

Most of the developed countries around the world have selected the chronological age of 65 years and above to refer to the older population, but this do not take into account specifically in Africa. On the other hand, the United Nation (UN) agreed to use the chronological age of 60 years and above as a guide for the definition of old [3]. By 2050, the number of world population ageing will be more than other age groups. The proportion of older people is estimated to rise from 12 percent in 2015 to more than 16 percent in 2030 [3]. In Thailand, the older people who are aged 60 years or over will increase more than 20 percent over the next five years [4].

Growth in the numbers of older population will increase the demand of health care, financial support, social protection and government support. Falls are the one of the leading causes of serious injury and hospital admissions in older people [7, 8].

2.2 Falls

2.2.1 Definition of falls

The Prevention of Falls Network Europe (ProFaNE) has developed the definition of falls as "an unexpected event in which the participant comes to rest on the ground, floor, or lower level" [19].

2.2.2 Prevalence of falls in older people

The incidence rate of falls has been reported to increase with age [20]. It has been estimated that 29-36% of people over 65 years of age fall each year [8, 21] increasing to 33-43% of those who are 70 years and over [22, 23]. The study of people ages 70 years and over showed that 40% of women fall each year, as compared with only 28% of men [12]. Falls occur more often in elderly living in nursing care than elderly living in community. A prospective study have reported that 30-50% of elderly living in nursing care fell in a one year period, and 39% of them experienced recurrent falls [24].

2.2.3 Consequences of falls

Falls are the leading cause of serious injury, hospitalization, loss of independence, morbidity and mortality in older people [25, 26]. About 60% of falls in older people result in minor injury, for example bruising and abrasions, [27] but an estimated 25% of falls result with serious injury including fracture [22]. Non-injurious falls are result in no physical injury, but can lead to fear of falling, loss of confidence and independence [28]. The costs of fall injuries are expected to double by 2020 [29].

2.2.4 Risk factors for falls in older people

The occurrences of falls among older people are often resulting from contributing factors. Risk factors that contribute to older people falling come under different categories. The panel on falls prevention consisting of members from the British Geriatric Society and American Geriatrics Society identified these risk factors as: (1) intrinsic factors and (2) extrinsic factors [30, 31, 32]

2.2.4.1 Intrinsic factors of falls

Intrinsic factors are age-related causes that affect balance, mobility, and daily activities such as weakness in the lower extremity, visual deficits, balance disorders, gait deficits, limited functional and cognitive impairment [32, 33, 34]. These physical issues affect the older people's ability to perform physical activities [35] such as dressing, toileting, eating, transferring, and bathing [36].

2.2.4.2 Extrinsic factors of falls

Extrinsic fall risk factors include environmental conditions such as wet floor, crowded walkways, unsafe stairways and poor lighting[31, 32]. Extrinsic factors also include the effects of certain types of medications and polypharmacy (when individuals have four or more prescription medications), as well as the side effects medications that contribute to the older people experiencing a fall.

2.3 Arthritis

2.3.1 Definitions and types

Arthritis is a debilitating chronic disease, resulting in joint swelling, inflammation, and pain. Arthritis is the cause of disability in older people [37]. Rheumatoid and osteoarthritis are the most prevalent forms of arthritis.

2.3.1.1 Rheumatoid arthritis

Rheumatoid is an autoimmune disorder, and results in inflammation and swelling in the wrists, hips, knees and feet [38].

2.3.1.2 Osteoarthritis

Osteoarthritis affects over 27 million Americans, and the prevalence of osteoarthritis is expected to rise [39]. A survey study among Thais ageing in the community found that the prevalence of knee osteoarthritis in older people aged over 50 years, with knee ranged from 34.5% to 45.6% [40]. Osteoarthritis can be divided in to primary osteoarthritis (e.g. genetics and aging) or secondary osteoarthritis (e.g. obesity, injury, and some metabolic disorders) [39]. Age is a major risk factor for osteoarthritis [41]. A few studies have identified associated between occupations with heavy lifting and osteoarthritis [42, 43]. A history of previous joint injury or trauma is considered a risk factors for osteoarthritis. A follow up study [44] revealed that people with previous knee joint injury had a 13.9% incidence rate of osteoarthritis compared to those without a history of injury had a 6% incidence rate.

Osteoarthritis is the leading cause of disability in older people aged over 65 years[37]. The current estimates of the prevalence of arthritis are that over 26 million Americans have some forms of osteoarthritis [10]. Approximately 10-30% of people with osteoarthritis living in the United States have pain and disability [45]. The World Health Organization estimates that 9.5% among men and 17% among women ages 60 years and over worldwide have symptomatic radiographic osteoarthritis [46]. Progression of osteoarthritis is usually slow but can impact physical activity and quality of life [48]. Osteoarthritis is a chronic joint condition that mostly affects the cartilage and tissues around the joint [49]. The main symptoms of osteoarthritis are stiffness, pain and limited range of motion [41]. The most commonly involved joints are hips, hands, knees, and the cervical and lumbar spine [10]. Osteoarthritis divided into two types: primary and secondary types. Primary osteoarthritis is mostly related to the genetic and aging process. Secondary osteoarthritis occurs as a result of another factors (i.e. repeated trauma, injury, obesity and some metabolic disorders) [39].

However, the major risk factor for osteoarthritis is age. Knee joint is most commonly affected by osteoarthritis in people aged 75 years and above [50].

2.3.1.3 Knee osteoarthritis

In 2005, one quarter of people aged 55 years or above experienced knee pain over the year [51]. Risk factors associated with knee osteoarthritis has been divided into three groups: systemic, local and loading factors. Systemic factors consisted of gender, older age, genetic predispositions and obesity. Local risk factors consisted of mis-shaped joints, mal-alignment, muscle weakness and proprioceptive deficiencies.

Osteoarthritis affect proprioception via different mechanisms. The joint effusion, mechanical damage or bony deformities may affect mechanoreceptors [52, 53], for example, inhibition of afferent fibers γ-motor neurons affects the sensitivity of muscle spindle [54]. In addition, osteoarthritis might affect accuracy of proprioceptive that may result in saturation of an afferent sensory neuron and reduce the ability to perform an accurate motion signal [56].

Proprioceptive deficits, pain, muscle weakness and altered neuromuscular control may lead to instability of the knee joint in people with knee osteoarthritis [57]. Self-reported knee instability was defined as the perception of giving way of the knee of previous three months [58]. Approximately 60–70% of the people with knee osteoarthritis reported of instability of the knee joint [59, 60, 61, 62]. Loss of muscle strength is related to functional instability of the knee [58].

There have been many studies reported that people with knee osteoarthritis commonly generate lower maximum forces on knee extensors and flexors muscle [63, 64, 65, 66, 67, 68] than healthy group [69, 70]. People with arthritis commonly experience muscle weakness. Quadriceps muscle strength deficits in people with arthritis affecting the knees have been reported up to 70% [54, 69, 70]. In knee osteoarthritis, decrease in the mass of the muscle by avoidance of activities and neuromuscular inhibition by knee pain can cause weakness of lower extremity muscle [69, 70].

Loading factors consisted of repetitive physical activities and obesity [71]. Additionally, the increased incidence of knee osteoarthritis may be attributable to higher obesity rates [72]. Knee osteoarthritis can affect structures of the knee: lateral tibiofemoral, medial tibiofemoral, and patellofemoral [39, 51]. The ground reaction force during walking creates a varus alignment inside the knee joint. (Figure 2.1)

The pain levels and limited movement can be affected by the severity level [39, 51]. The most commonly affected area is the medial part of tibiofemoral joint taking approximately 75% of the joint load during walking [73]. Particularly, the imbalance between lateral and medial compartment of the knee joint occurs even in normal lower limb alignment. Varus alignment shifts the load medially to the knee, increasing even more load through the medial compartment [74, 75].

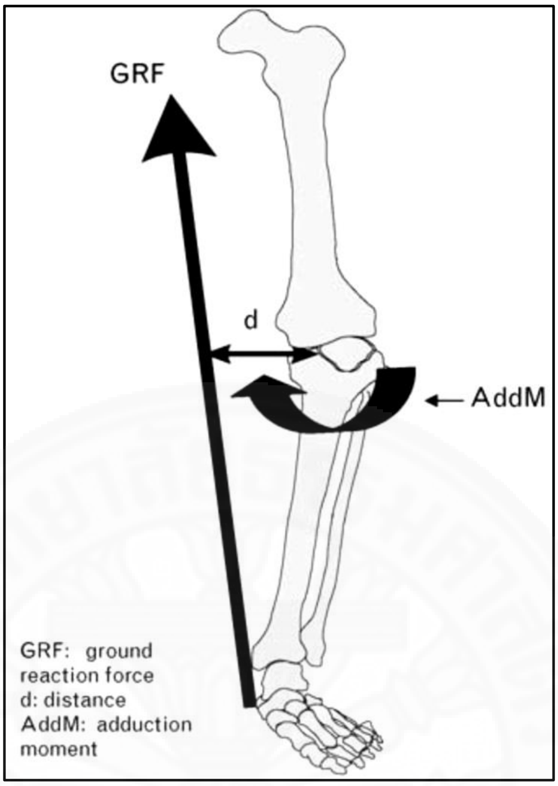

Figure 3.1 Knee joint adduction moment [2]

High repetitive force on the knee joint during walking are the most factors leading to knee osteoarthritis [76, 77]. Loading of the knee joint during walking are not equally between the lateral and medial compartments. The load inside of the knee is 2.5 times greater than the lateral compartment [67]. This imbalance in the loads on the knee joint may explain higher knee osteoarthritis prevalence between medial compartment (75% of knee osteoarthritis) than lateral compartment (25% of knee osteoarthritis) [78]. Primary factors include high body weight, job, and involvement in high level sport. Obesity increases load and force on the knee joint during [79, 80, 81, 82].

2.3.2 Osteoarthritis and falls

Generally, pain may have a negative impact on coordination, muscle strength, proprioception, and postural sway, factors that further increasing risk of fall-related injuries [70]. Pain, proprioception, strength and balance impairment associated with knee osteoarthritis, contribute to increased fall risk among people with knee osteoarthritis [83]. It has been reported that the frequency of falls in older people living in community with severe knee osteoarthritis is higher than the 30%, since those people have many risk factors such as pain , increasing age, low quality of life and impaired mobility [83]. Self-reported knee instability have been studied and shown that muscle weakness is a contributing factor to increase the incidence of falls in knee osteoarthritis [58, 84]. A study also reported the identification of knee extension strength as an predictor of falls in elderly with arthritis [85]. Those results were based on self-reported of older people with nonspecific arthritis of the lower extremity. In addition, it has been reported that knee extension strength was correlated with falls [83]. Loss of proprioception are greater in people with knee osteoarthritis [86, 87, 88, 89] which may affect balance and increase falls risk. The impairment of postural stability is a factor leading to falls in older people [91]. Falls and balance deficit tending to occur more frequently during walking [92]. Therefore, gait impairments in people with osteoarthritis are associated with risk of falls [93].

2.4 Gait

2.4.1 Definition

Walking is defined as "a method of locomotion involving the use of the two legs, alternately, to provide support and propulsion with at least one foot being in contact with the ground at all times" [94]. While the terms of walking and gait appear to be used in the place of each other, describing gait as "the manner or style of walking", rather than the process of walking [94].

2.4.1.1 Gait cycle

A gait cycle begins when the foot contact the floor and ending with the same foot contact the floor[94]. Gait cycle consist of stance and swing phase.

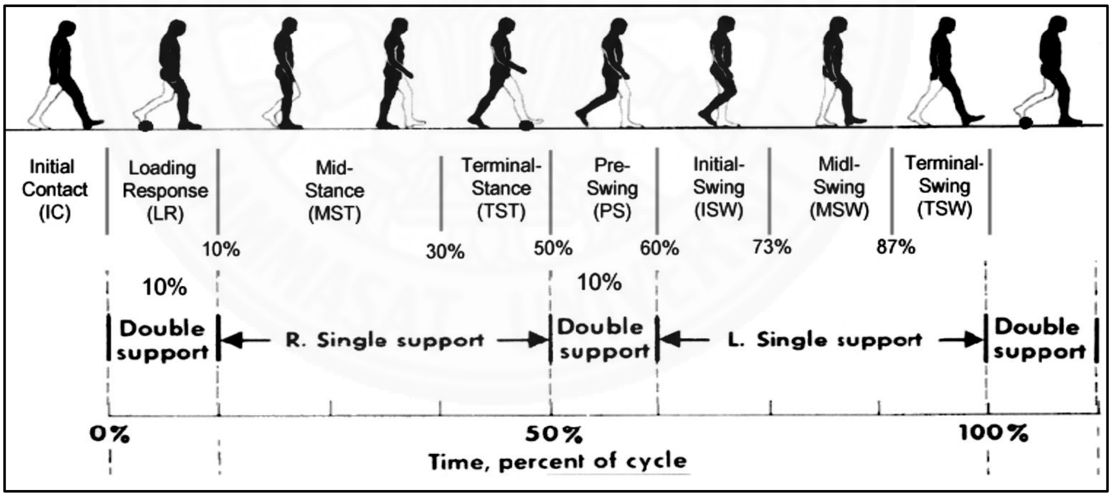

Figure 3.2 Phases of a gait cycle [1]

Each gait cycle, 60% of the gait cycle and only 40% of gait cycle is represented by stance phase and swing phase [1]. Five phases of stance phase consists of: initial contact, loading response, mid stance, terminal stance and pre-swing. Swing phase is divided into three phases: initial swing, mid swing and terminal swing [1] (Figure 2.2).

2.4.2 Gait biomechanics

2.4.2.1 Spatiotemporal gait

Spatiotemporal variables of gait consist of cadence, stride length, step length, double support time and gait speed (Figure 2.3) [94, 95]. Stride length is measured as the distance between heel strikes to the following heel strikes of the same foot, while step length is measured as the distance between heel strikes of the opposite foot [96]. Cadence is the number of times that foot contact the ground during a given amount of time. The average stride time can be calculated by the resulting cadence. Gait speed is determined by using the cadence (stride frequency) and stride length values through the equation: walking speed = (cadence x stride length) / 120 [94, 95].

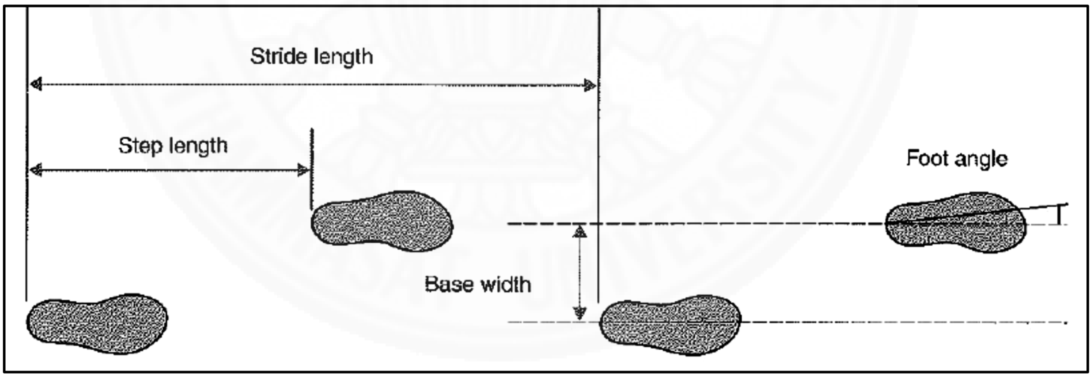

Figure 3.3 Gait analysis spatial terminology [1]

2.4.2.2 Gait kinematics

Gait kinematics is the study of the motion without considering the forces that caused the motion (kinetics) [94], and describes the gait variables in terms of angular displacements [95].

(1) Hip motion

Normally, the full range of motion in the hip joint is approximately 40 degrees of motion in the sagittal plane, 9 degrees of motion in the coronal plane and 12 degrees of motion in the transverse plane. In quiet standing, using 0 degrees (zero position) as a reference point of hip extension, the hip reaches up to 10 degrees of extension and 30 degrees of flexion. The hip at initial contact is flexion to 20 degrees. During mid-stance, the hip begins extend until it reaches 10 degrees of extension before toe-off. Maximum flexion occurs during the mid-swing to ensure toe clearance [1] (Figure 2.4).

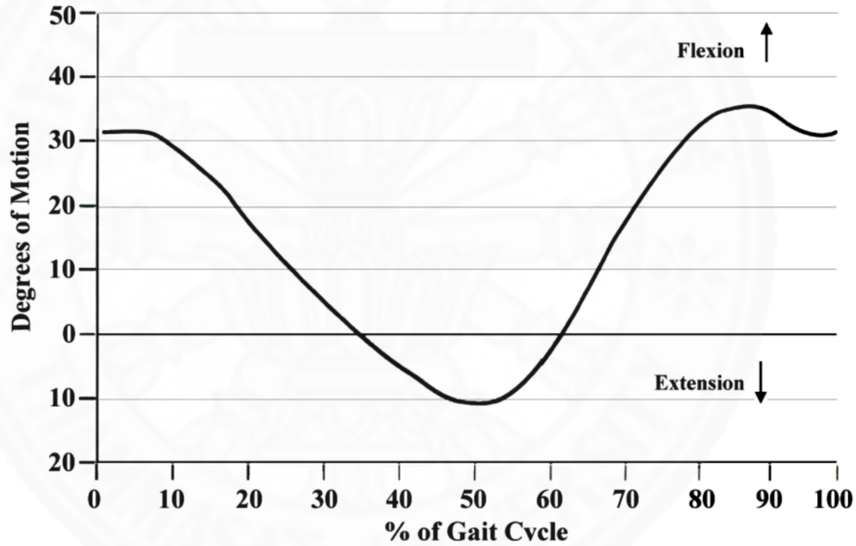

Figure 3.4 Hip flexion and extension during healthy gait [1]

(2) Knee motion

The kinematics of knee movement in three planes involves the relative motion of tibia and femur. Normally, the full range of motion in the knee joint is about 70 degrees of movement in the sagittal plane, 0-12 degrees of movement in the coronal plane and 13 degrees of movement in the transverse plane. At initial contact, the knee joint is slightly flexion to 5 to 10 degrees of movement in the sagittal plane. During the onset of stance phase, the knee flexes reaching approximately 20 degrees. In mid-stance, the knee extends from flat foot until heel off. Then, the knee flexes a second time to 7 degrees of flexion after heel off and continues during the swing phase, reaching 40 degrees of knee flexion in pre-swing and 60 degrees of knee flexion in initial swing. The knee reaches maximum just before initial contact. The peak knee extension is ranges from 3 degrees of hyperextension to 5 degrees of flexion [1] (Figure 2.5).

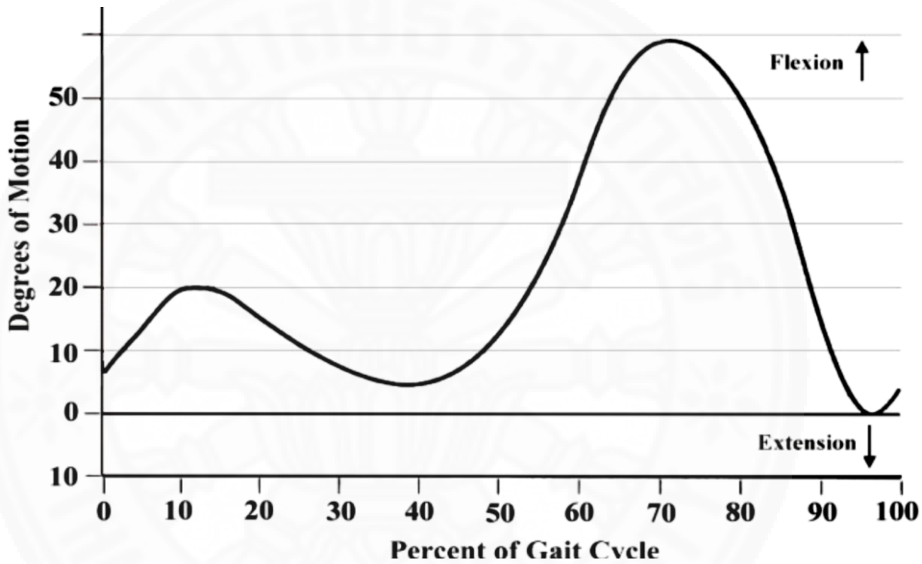

Figure 3.5 Knee flexion and extension during healthy gait [1]

(3) Ankle and foot motion

The ankle joint is in a neutral position during initial contact. After initial contact, the ankle is rapid plantar flexion to approximately 7 degrees. As the body move over the stationary foot, the ankle dorsiflexes from foot flat to heel-off and followed by rapid ankle plantar flexion of approximately 20 degrees at the time of toe-off. The ankle joint returns to the neutral position during swing phase [1] (Figure 2.6).

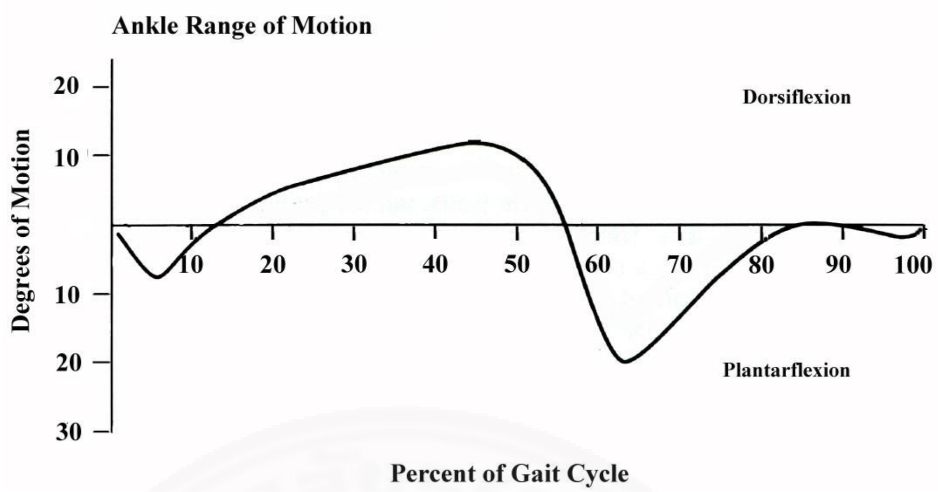

Figure 3.6 Ankle plantar flexion and dorsiflexion during healthy gait [1]

2.4.3 Gait analysis

Gait analyses is used to assess the effectiveness of interventions such as physiotherapy and surgery [98]. In order to conduct the gait analysis, reflective spherical markers are placed on the participant's body. When the participant walks along the walkway, the markers positions are capture with a 3D video cameras [99]. The motion capture system consists of at least two video cameras. The red infrared light, reflected by the markers and returned to the cameras to determine the marker positions [99].

2.4.3.1 Reliability of 3D gait analysis

Multiple reliability of gait analysis studies have evaluated the healthy individuals [97, 98, 100, 101, 102, 103, 104]. Reliability studies have been done on subjects with gait pathology, such as:

(1) Children with cerebral palsy [105, 106]

(2) Adults with stroke [107, 108]

(3) Adults with osteoarthritis [109, 110]

(4) Adults with traumatic brain injury [111]

Measurement errors and variability in 3D gait analysis can result from different sources [112] such as:

(1) Subject

- Laboratory setting
- Footwear
- Gait speed
- Variations of gait

(2) System

- Number of cameras
- Digitizing of video analysis
- Calibration

(3) Assessor

- Anthropometric measurement
- Marker placement
- Different assessor
- Identification of anatomical landmarks
- Statistical analysis
- Data processing

2.4.4 Osteoarthritic gait

The proprioception and muscle strength are the maintenance of vertical standing balance [118, 119] and control body motion while walking. If quadriceps muscle function are significantly impaired this may affect balance and gait in individuals with knee osteoarthritis.

2.4.4.1 Spatiotemporal variables

The spatiotemporal gait variables examined were cadence, walking speed, stance duration, stride duration and stride length. The studies of knee osteoarthritis versus controls have been reported that the effect of knee osteoarthritis on spatiotemporal gait variables are dependent on disease severity and suggested that those with severe knee osteoarthritis exhibited significantly greater stride time than healthy controls [120, 121, 122] and reduction in cadence [120, 121, 122, 123]. Most studies of gait deviations in knee osteoarthritis showed a decrease in both of the gait speed and stride length [120, 121, 122, 123]. Moreover, the studies between severe and moderate knee osteoarthritis groups have been reported that those with severe knee osteoarthritis exhibited longer stride time [120, 121, 124] and reduced walking speed [66, 120, 121, 124, 125] and stride length [66, 120, 121, 124].

2.4.4.2 Joint kinematics

The kinematic gait variables associated with knee osteoarthritis during gait such as hip adduction, knee extension, knee flexion at initial contact and lateral trunk lean. It has been reported that subjects with moderate knee osteoarthritis and varus alignment showed a reduction in knee flexion angle during stance phase and increase knee flexion angle during initial contact compared with the control group [126, 127, 128]. For the control group and people with severe knee osteoarthritis exhibited large reductions were reported knee flexion excursion [129] and peak hip adduction during stance phase [121, 123, 130]. On the other hand, it has been reported for knee extension at several different gait speeds between those with severe knee osteoarthritis and healthy controls [130]. Previous studies found no difference in lateral trunk lean [129, 131, 132], and knee angle between people with mild knee osteoarthritis and healthy controls [131].

The gait biomechanics of people with knee osteoarthritis have been widely reported, although they have mainly focused on the frontal and sagittal planes [121, 135, 136, 137]. In level walking, the osteoarthritis group had 6° less peak knee flexion than the healthy group and cadence was also significantly reduced during walking for the osteoarthritis group [138]. At weight acceptance, the people with moderate medial compartment knee osteoarthritis had significantly smaller knee flexion and greater adduction angle of the involved side than on the uninvolved side [139]. Two studies reported that people with bilateral knee osteoarthritis had more knee extension at initial contact than the control group [140, 141]. On the other hand, two studies reported that people with knee osteoarthritis had greater knee flexion at initial contact [142, 143]. Moreover, a study assessed the gait adaptions of the knee with early and established osteoarthritis in comparison with a control group. The gait analysis variables were acquired using 3D motion analysis. No significant differences were found in angular displacement between the early osteoarthritis and healthy group [144]. Early osteoarthritis group showed less knee adduction during stance phase and more knee extension in the end of stance phase than established osteoarthritis group.

There are common gait features which are consistently shown to be significantly linked to osteoarthritis severity such as knee adduction moment, knee flexion angle and walking speed. Some studies have examined kinematic during phase-specific gait cycle and reported a decreased knee excursion during flexion, decreased peak knee flexion at stance phase and increased knee flexion at heel strike [133, 145]. Table 2.1 summarized material and methods of gait characteristics measurements in people with knee osteoarthritis studies.

Table 3.1 Material and methods of gait characteristics measurements in people with knee osteoarthritis studies

Authors	Subjects	Method	Activity studied	Flexion/ Extension	Adduction/ Abduction
Kaufman et al (2001) [138]	139 patients knee osteoarthritis and 20 control group	Reflective markers, six video cameras	walking stair ascent stair descent	↓ peak motion	-
Briem et al (2009) **[139]**	32 patients with medial knee osteoarthritis (Inter-limb differences)	Optoelectronic motion analysis	gait, stance phase	↓ flexion	↑ adduction
Mündermann et al (2005) [140]	42 patients with medial knee osteoarthritis and 42 control group	Reflective markers	gait, stance phase	↓ flexion at heel strike	-
Heiden et al (2009) **[142]**	54 patients knee osteoarthritis and 30 control group	Reflective cluster markers	gait, stance phase	↑ flexion at heel strike	-

Table 2.1 Material and methods of gait characteristics measurements in people with knee osteoarthritis studies (Cont.)

Authors	Subjects	Method	Activity studied	Flexion/ Extension	Adduction/ Abduction
Deluzio et al (2007) [146]	50 patients knee osteoarthritis and 63 control group	Optoelectronic system	gait	↓ flexion	-
Nagano et al (2012) [141]	45 patients knee osteoarthritis and 13 control group	Reflective cluster markers	gait, foot contact and 50% of stance phase	↓ flexion	↓ abduction
Childs et al (2004) [143]	24 patients knee osteoarthritis and 24 control group	Electromagnetic motion analysis system	gait, stance phase	↑ flexion at heel strike	-
Landry et al (2007) [131]	41 patients knee osteoarthritis and 43 control group	Optoelectronic system	gait	-	-

Table 2.1 Material and methods of gait characteristics measurements in people with knee osteoarthritis studies (Cont.)

Authors	Subjects	Method	Activity studied	Flexion/ Extension	Adduction/ Abduction
Baert et al (2013) [147]	14 female early knee osteoarthritis, 12 female established knee osteoarthritis and 14 female control group	3D motion analysis (LED)	gait	↓ extension in stance	↑ adduction

CHAPTER 3
RESEARCH METHODOLOGY

This chapter details the methodology that was used for investigating the gait characteristics in older people with knee osteoarthritis, especially when associated with falls. The target of population, inclusion and exclusion criteria, number of the participants, and measures and measurement procedures are also described in detail in this chapter.

3.1 Participants

The inclusion and exclusion criteria of the older people with and without knee osteoarthritis group are as follows.

3.1.1 Older people with knee osteoarthritis group

3.1.1.1 Inclusion criteria

(1) People aged 60 years and over who had a diagnosis of knee osteoarthritis.

(2) Able to walk independently for at least 10 meters.

3.1.1.2 Exclusion criteria

(1) No history of lower limb joint replacement

(2) No history of neurological disorders

(3) No history of previous knee operation

(4) No history intra-articular injection in the previous six months

(5) No history of musculoskeletal or cardiopulmonary disorders that could limit walking ability.

3.1.2 Older people without knee osteoarthritis group

3.1.2.1 Inclusion criteria

(1) People aged 60 years and over

(2) Able to walk independently for at least 10 meters.

3.1.2.2 Exclusion criteria

(1) No history of lower limb joint replacement

(2) No history of neurological disorders

(3) No history of previous knee operation

(4) No history of musculoskeletal or cardiopulmonary disorders that could limit walking ability.

3.2 Sample size

The formula for estimating sample size is given as:

$$n = \left(\frac{r+1}{r}\right)\frac{\sigma^2(Z_\beta + Z_{\frac{\alpha}{2}})^2}{(\text{difference})^2}$$

- n = Sample size in the osteoarthritis group.
- $(\frac{r+1}{r})$ = Ratio of older people without knee osteoarthritis to older people with knee osteoarthritis group. (r=1 equal number of cases and controls)
- Z_α = Represents the desired level of statistical significance (For 0.05 significance level, Z_α=1.96).
- Z_β = Represents the desired power (For 80% power, Z_β= .84).
- σ^2 = Standard deviation of the outcome variable (σ^2=5.56) [126]
- $(\text{difference})^2$ = Effect size (the difference in means) [126]

$$n = (1)\frac{5.65(0.84 + 0.98)^2}{(0.88)^2}$$

$$n = 24/\text{ group}$$

Number of participants = 48 (24 cases, 24 controls) would be required for the study.

3.3 Instrumentation

Assessments consisted of following measurements: i) history of falls; ii) gait characteristics (kinematic and spatiotemporal data); and iii) WOMAC (knee pain, stiffness and functional ability). The information of each measure is detailed in the section below.

3.3.1 Data collection forms

3.3.1.1 The demographic variables data form

The demographic variables included age, sex, marital status, education, employment, underlying disease and medication.

3.3.1.2 The physical examination

(1) Proprioception was measured by the ACUMAR^{TM} digital inclinometer. The absolute angular error was used for measurement of joint position sense. The absolute angular error is the difference between the reposition angle and the target angle. The digital inclinometer was placed on the lateral ridge of the femur and tibia. The testing was performed in the sitting position. The starting position was performed in full knee extension. The participants were instructed to close their eyes, and extend their knee to full range of motion and then slowly bend the knee at the target angles of 30° and 80°. This angle was held for 5 seconds, during each time the participants were instructed to remember the joint position. Then, the participants returned to the starting position, and held for 5 seconds before reposition to the target angle. The participants replaced their leg to where they believed is the target angle and this angle is the reposition angle. The absolute angular error was calculated as the difference between the target angle and reposition angles. The absolute angular error of each target angle was measured three times and the mean value of the three measurements was used in the analysis.

(2) Muscle strength was measured using the hand held dynamometer (HHD). The participants seated on a chair in an upright position. Their hips and knees were positioned at 90° flexion. The HHD was applied on the anterior aspect of the tibia, 5 cm proximal of the lateral malleolus [148]. Each participant performed four trials that consisted of one warm-up and three maximal isometric knee

contractions for both flexion and extension. Each contraction was held for five second. The mean of three maximal isometric knee contractions measures was calculated. The testing was performed on the uninvolved leg, followed by the involved leg. One minute of rest was taken between each trial.

3.3.1.3 The history of falls data form

History of self-reported falls were collected using the record form related to frequency of falls, activities prior to falling, causes of falls, perceived cause and injuries sustained from falls [19, 149].

3.3.1.4 The Western Ontario McMaster Universities Osteoarthritis Index (WOMAC)

The Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) is a self-reported of joint pain, joint stiffness, and physical function disability in people with knee osteoarthritis. The questionnaire is self-administered with 24 questions divided into 3 subscales: joint pain (5 items), stiffness (2 items) and physical function disability (17 items). Each score will be summed to produce a total scores for each subscale: pain (0-45), stiffness (0-18), and functional ability (0-153). The WOMAC is an evaluation tool for the people with knee osteoarthritis [150, 151, 152, 153].

The WOMAC index was translated into Thai language following standard guidelines, back-translated, tested for validity and reliability, and then modified. Two items of the WOMAC (items F05 and F12) that had an ICV of 0 were removed from the questionnaire [154].

3.3.2 Gait analysis

The data were collected using the VICON^{TM} Motion System. Instrument and materials consist of:

- Eight video cameras
- Calibration wand (L-frame)
- Thirty-five reflective spherical markers (1.4 cm diameter)
- Double-side tape
- Anthropometric measurements data form
- Vernier caliper
- Tape measure

3.4 Outcome measures

3.4.1 Primary outcomes

3.4.1.1 Spatiotemporal data

Variables comparing between the older people with and without knee osteoarthritis group consist of:

- Cadence (steps/min)
- Step length (m)
- Step time (s)
- Stride length (m)
- Stride time (s)
- Gait velocity (m/s)
- Single support time (s)
- Double support time (s)

3.4.1.2 Kinematic data

Angular displacement of the hip, knee, and ankle were measured at the initial contact, mid stance, toe off and mid swing events.

3.4.1.3 History of self-reported falling

A questionnaire that questions the data related to frequency of falls, activities prior to falling, causes of falls, perceived cause and injuries sustained from falls.

3.4.2 Secondary outcome measures

3.4.2.1 The modified Thai Western Ontario McMaster Universities Osteoarthritis index (WOMAC)

The questionnaire is a self-reported of joint pain, joint stiffness, and physical function disability in people with knee osteoarthritis [154].

3.5 Procedure

Each participant were invited to the motion laboratory, Faculty of Allied Health Sciences, Thammasat University for gait and falls assessment. The researcher informed participants for the aim, procedures, risks and benefits of the study before participating in this study.

3.5.1 Physical examination

Researcher recorded the demographic data and assessed proprioception and muscle strength.

3.5.2 Preparing participants for marker placement

Before collecting data, participants were asked to change their clothes and remove their accessories. Participants were then asked to wear a black tank top and short pants.

3.5.2.1 Anthropometric data measurements

Anthropometric data including body weight, height, shoulder offset, elbow width, wrist width, hand thickness, leg length, knee width and ankle width were measured prior to marker attachment as shown in Table 3.1.

Table 4.1 Plug-in gait full body models

Subject	Required	Measurements optional
General	Body mass (kg)	Subject mass
	Height (mm)	Subject height
Upper body	Elbow width (mm)	The distance between the medial and lateral epicondyles of the humerus. (Width of elbow along frontal axis)
	Hand thickness (mm)	The thickness between the dorsum and palmar surfaces of the hand.
	Shoulder offset (mm)	The distance between base of the acromion process to shoulder joint center.
	Wrist width (mm)	Anterior/Posterior thickness of wrist at position where wrist marker bar is attached.
Lower body	Inter-ASIS distance (mm)	The distance between the left ASIS and right ASIS. This measurement is only needed when markers cannot be placed directly on the ASIS, for example, in obese people.
	Ankle width (mm)	The medio-lateral distance across the malleoli. Measure in standing position, if possible.
	Knee width (mm)	The medio-lateral width of the knee across the line of the knee axis. Measure in standing position, if possible.
	Leg length (mm)	The distance between the ASIS marker and the medial malleolus, via the knee joint. Measure in standing position, if possible.

3.5.2.2 Marker placement

Thirty-five reflective spherical markers were attached on participants' body as shown in Table 3.2 and Figure 3.1.

Table 4.2 Marker placement

Marker label	Definition	Position on participant
Head marker		
1. LFHD	Left front head	Left temple (the side of the head behind the eyes. The bone beneath is the temporal bone as well as part of the sphenoid bone.)
2. RFHD	Right front head	Right temple (the side of the head behind the eyes. The bone beneath is the temporal bone as well as part of the sphenoid bone.)
3. LBHD	Left back head	Left back of the head, in a horizontal plane of the front head markers.
4. RBHD	Right back head	Right back of the head, in a horizontal plane of the front head markers.
Torso marker		
5. C7	7th cervical vertebrae	On the spinous process of the 7^{th} cervical vertebra
6. T10	10th thoracic vertebra	On the spinous process of the 10^{th} thoracic vertebra
7. CLAV	Clavicle	On the jugular notch where the clavicles meet the sternum

Table 3.2 Marker placement (Cont.)

Marker label	Definition	Position on participant
8. STRN	Sternum	On the xiphoid process of the sternum
9. RBAK	Right back	Anywhere over the right scapula (This marker has no equivalent marker on the left side. This asymmetry helps the auto labeling routine determine right from left on the subject.)
Upper limb markers		
10. LSHO	Left shoulder	On the acromio-clavicular joint
11. RSHO	Right shoulder	
12. LELB	Left elbow	On the lateral epicondyle approximating the elbow joint axis
13. RELB	Right elbow	
14. LWRA	Left wrist marker A	At the thumb side of a bar attached to a wristband on the posterior of the wrist, as close to the wrist joint center as possible.
15. RWRA	Right wrist marker A	

Table 3.2 Marker placement (Cont.)

Marker label	Definition	Position on participant
16. LWRB	Left wrist marker B	At the little finger side of a bar attached to a wristband on the posterior of the wrist, as close to the wrist joint center as possible.
17. RWRB	Right wrist marker B	
18. LFIN	Left finger	Just proximal to the middle knuckle on the hand
19. RFIN	Right finger	
Lower body markers		
20. LASI	Left ASIS	Left anterior superior iliac spine
21. RASI	Right ASIS	Right anterior superior iliac spine
22. LPSI	Left PSI	Left posterior superior iliac spine (immediately below the sacro-iliac joints, at the point where the spine joins the pelvis)
23. RPSI	Right PSI	Right posterior superior iliac spine (immediately below the sacro-iliac joints, at the point where the spine joins the pelvis)
24. LTHI	Left thigh	Over the lower lateral 1/3 surface of the thigh in line with the hip and knee joint centers
25. RTHI	Right thigh	

Table 3.2 Marker placement (Cont.)

Marker label	Definition	Position on participant
26. LKNE	Left knee	On the flexion-extension axis of the knee
27. RKNE	Right knee	
28. LTIB	Left tibia	Over the lower 1/3 surface of the shank
29. RTIB	Right tibia	
30. LANK	Left ankle	On the lateral malleolus
31. RANK	Right ankle	
32. LHEE	Left heel	On the calcaneus at the same height above the plantar surface of the foot as the toe marker.
33. RHEE	Right heel	
34. LTOE	Left toe	Over the second metatarsal head, on the mid foot side of the equinus break between forefoot and mid-foot.
35. RTOE	Right toe	

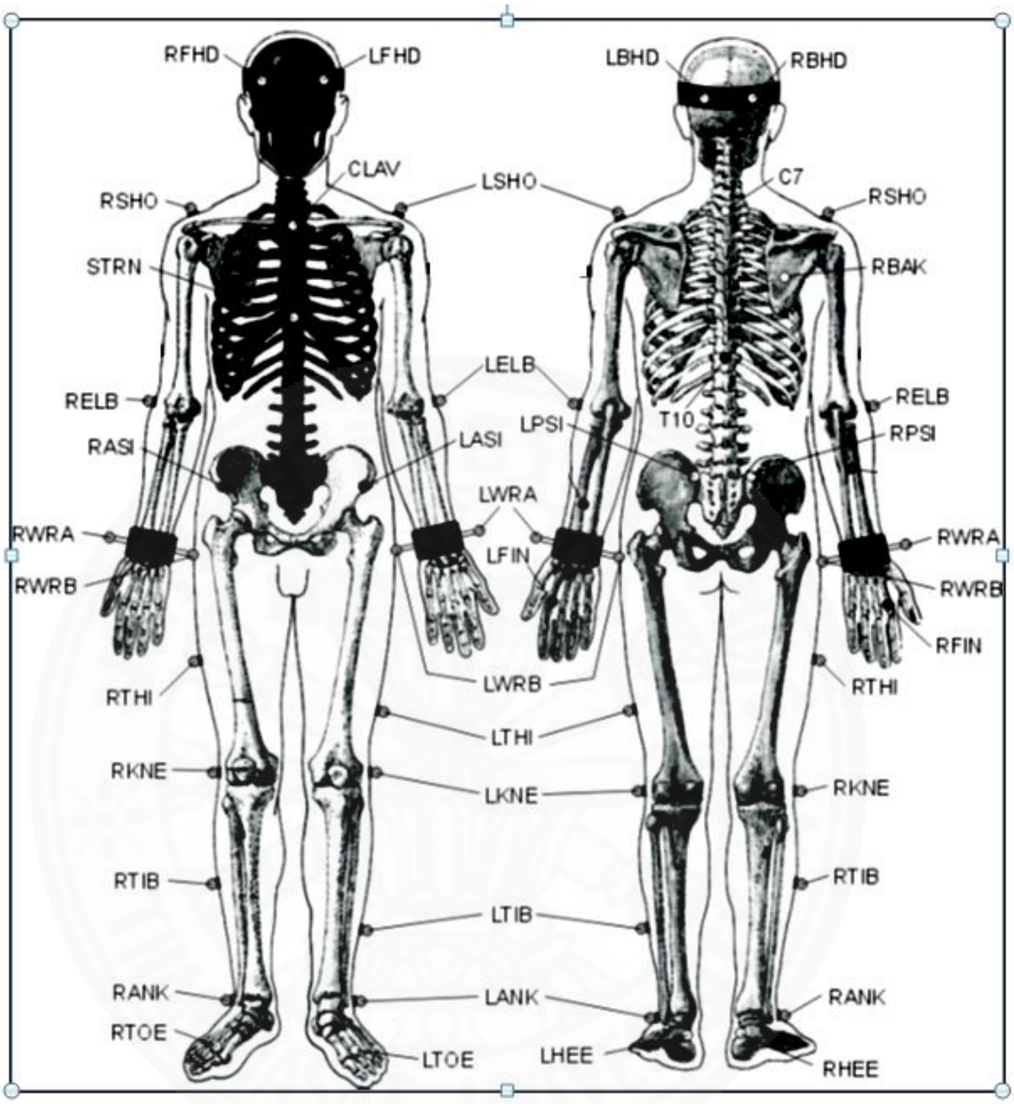

Figure 4.1 Plug-in-Gait model (Adapted from VICON^{TM}, Polygon manual)

3.5.3 Data collection

3.5.3.1 Plug-in Gait static trial

All participants were asked to stand in the comfortable position with arms extended by their side and looking straight ahead. Data were collected by eight video camera of VICON^{TM} Motion System for ten seconds.

3.5.3.2 Walking data collection

Participants were asked to walk with bare feet at self-selected speeds along the 10 meters walkway (Figure 3.2). Researcher walked along the participants to prevent falling or accidental situations. Three successful walking trials were collected. The diagram shows the process of data collection (Figure 3.3).

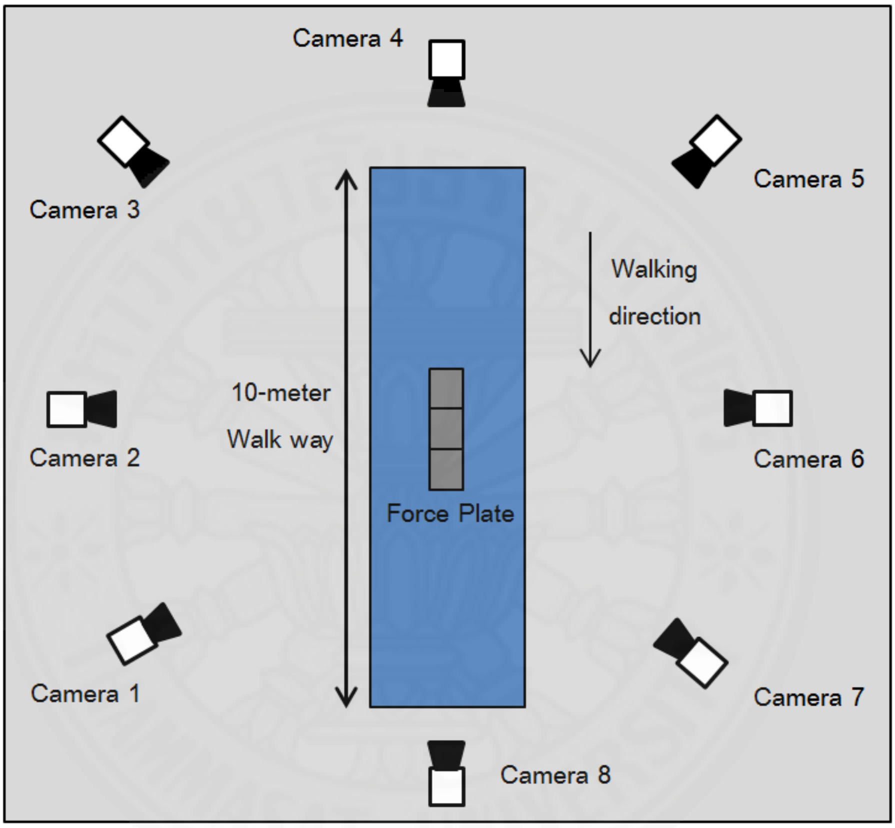

Figure 4.2 The diagram of the motion laboratory at the Faculty of Allied Health ciences, Thammasat University.

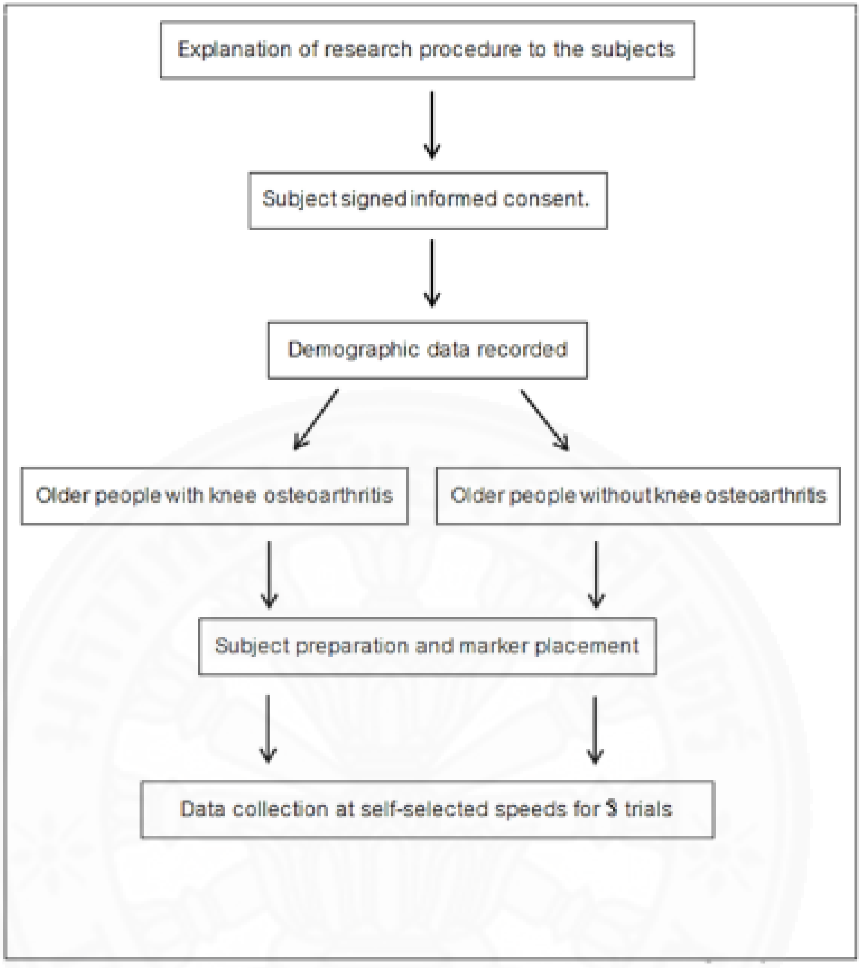

Figure 4.3 The diagram shows the potential process of data collection.

3.6 Statistical analyses

First, Kolmogorov-Smirnov statistic was used to determine data normal distribution. To compare demographics data (e.g., age, height, and weight), WOMAC score and gait characteristics (e.g., kinematic and spatiotemporal data) between control and osteoarthritis groups, the independent t-test was used if the data are normally distributed or Mann-Whitney was used if the data were not normally distributed. Point biserial correlation was used to measure the correlation between gait characteristics (kinematic and spatiotemporal data) and history of falls in older people with knee osteoarthritis. The SPSS statistics version 17 was used for data analysis. The significant level (α) was set at $p < 0.05$.

CHAPTER 4
RESULTS

4.1 Participant characteristics

Twenty-four participants with knee osteoarthritis (mean age 66.21 years, range 60-84 years) and 24 healthy older people (mean age 65.67 years, range 60-80 years) were recruited. The demographic and clinical characteristics of the participants are shown in Table 4.1. No significant differences were observed between groups regarding gender, age, weight, height, BMI or number of medication. All participants with osteoarthritis were categorized as having mild to moderate pain and physical disability. Knee joint position sense of the osteoarthritis group was significantly worse than the control group and knee extension force of the osteoarthritis group were significantly poorer than the control group. There was no significant difference to the number of fallers between groups.

Table 5.1 Comparison of means and standard deviations of participant characteristics between participants with osteoarthritis and control group

Characteristics	Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Gender (male: female), (n)	6:18	7:17	0.748
Mean age (years)	66.21 ± 6.53	65.67 ± 4.68	0.992
Mean weight (kg)	62.66 ± 11.51	62.50 ± 9.55	0.893
Mean height (cm)	152.45 ± 6.74	154.66 ± 7.86	0.302
Mean BMI (kg/m^2)	27.03 ± 4.95	26.10 ± 3.27	0.448
Number of medical condition, median (range)	2 (4)	1 (4)	0.036*
Number of medication, median (range)	1 (4)	1 (3)	0.755
Painful knee, n (%) - Left side - Right side	 11 (45.8) 13 (54.2)	 - -	-
Leg dominant pain, n (%) - Dominant side - Non-dominant side	 13 (54.2) 11 (45.8)	- -	-
Knee joint position sense (error angle (°))	8.61 ± 3.16	2.41 ± 9.88	<0.01*
Knee extension force (N)	261.11 ± 14.58	266.14 ± 48.06	<0.01*
Mean modified WOMAC score - Pain - Stiffness - Function - Total scores	 18.58 ± 7.27 6.12 ± 4.12 44.38 ± 18.84 69.08 ± 25.51	 0.67 ± 1.43 0.38 ± 1.13 1.13 ± 3.16 2.17 ± 5.43	 <0.01* <0.01* <0.01* <0.01*
Faller, n (%)	1 (4.2%)	4 (16.7%)	0.161
Number of falls in previous 1 month, n (%) - One falls	 -	 1 (4.2%)	0.317

Table 5.2 Comparison of means and standard deviations of participant characteristics between participants with osteoarthritis and control group (Cont.)

Characteristics	Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Number of falls in previous 6 months, n (%)			0.317
- One falls	-	1 (4.2%)	
Number of falls in previous 12 months, n (%)			0.572
- One falls	-	1 (4.2%)	
- Two falls	1 (4.2%)	1 (4.2%)	
Causes of falls			0.161
- Tripped	-	2 (8.3%)	
- Missed curb or step	1 (4.2%)	-	
- Slipped	-	2 (8.3%)	
Activity during falls			
- Walking	-	4 (16.17%)	
- Climbing stairs	1 (4.2%)	-	
Injuries during falls			0.145
- No injury	1 (4.2%)	1 (4.2%)	
- Contusions/ abrasions	-	3 (12.5%)	
Falls witness	1 (4.2%)	-	0.139
Seeing a doctor after falls	1 (4.2%)	1 (4.2%)	0.145
Falls direction			0.173
- Front	-	2 (8.3%)	
- Back	1 (4.2%)	2 (8.3%)	

Note: *= Significant difference between participants with osteoarthritis and the control group at p-value < 0.05

WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index (maximum score = 120) (higher score implies severe osteoarthritis)

4.2 Comparisons of gait characteristics (spatiotemporal variables and kinematics data) between older people with and without knee osteoarthritis

4.2.1 Spatiotemporal variables

Spatiotemporal variables were compared between participants with osteoarthritis and the control group. Mean values and standard deviations of spatiotemporal variables including velocity, cadence, step length, stride length, step time, stride time, single support time and double support time are shown in Table 4.2. There were significant differences in all variables between participants with osteoarthritis and the control group. Velocity, cadence, step length, single support time and stride length of the osteoarthritis group were significantly less than the control group, whereas step time, stride time and double support time of the osteoarthritis group were significantly greater than the control group.

Table 5.3 Comparison of means and standard deviations of spatiotemporal variables between participants with osteoarthritis and the control group

Variables	**Osteoarthritis (n=24)**	**Controls (n=24)**	***p*-value**
Velocity (m/sec)	0.85 ± 0.16	1.02 ± 0.16	0.001*
Cadence (step/min)	100.84 ± 12.23	108.45 ± 9.12	0.025*
Step time (sec)	0.60 ± 0.07	0.55 ± 0.04	0.019*
Step length (m)	0.50 ± 0.06	0.57 ± 0.09	0.003*
Stride time (sec)	1.21 ± 0.15	1.11 ± 0.11	0.024*
Stride length (m)	1.01 ± 0.10	1.13 ± 0.14	0.003*
Single support time (% cycle)	31.92 ± 2.70	33.39 ± 2.37	0.039*
Double support time (% cycle)	36.02 ± 5.58	32.82 ± 4.55	0.043*

Note: *= Significant difference at p-value < 0.05

4.2.2 Gait kinematics (degrees)

Number of participants showed the different trends of the angular displacement of hip, knee and ankle in all three planes of movement during initial contact, mid stance, toe off and mid swing events are shown in Table 4.3.

Table 5.4 Number of participants showed the different trends of the angular displacement of hip, knee and ankle in all three planes of movement during initial contact, mid stance, toe off and mid swing events

Event	Joint	Action	Osteoarthritis Mean ± SD (n)	Controls Mean ± SD (n)
Initial contact	Hip	Flexion (+)	31.86 ± 6.04 (24)	29.90 ± 6.17 (24)
		Extension (-)	-	-
		Adduction (+)	2.42 ± 2.55 (4)	0.73 ± 1.04 (5)
		Abduction (-)	-4.16 ± 2.00 (20)	-3.09 ± 2.62 (19)
		Internal (+)	8.97 ± 8.48 (3)	2.17 ± 3.34 (4)
		External rotation (-)	-10.20 ± 12.41 (21)	-5.97 ± 2.62 (20)
	Knee	Flexion (+)	7.73 ± 4.56 (22)	4.31 ± 2.92 (21)
		Extension (-)	-6.84 ± 2.56 (2)	-1.23 ± 1.08 (3)
		Varus (+)	6.10 ± 3.38 (20)	3.42 ± 2.57 (13)
		Valgus (-)	-1.78 ± 1.54 (4)	-1.44 ± 1.52 (11)
		Internal (+)	-	-
		External rotation (-)	-12.64 ± 5.41 (24)	-8.32 ± 3.38 (24)
	Ankle	Dorsiflexion (+)	6.96 ± 4.78 (22)	5.52 ± 2.62 (23)
		Plantarflexion (-)	-3.54 ± 4.82 (2)	-1.40 (1)
		Inversion (+)	3.43 ± 1.97 (6)	1.02 (1)
		Eversion (-)	-3.79 ± 2.66 (18)	-4.26 ± 2.17 (23)
		Internal (+)	1.42 ± 2.36 (4)	0.67 ± 1.19 (5)
		External rotation (-)	-3.16 ± 2.40 (20)	-2.09 ± 2.62 (19)

Table 5.5 Number of participants showed the different trends of the angular displacement of hip, knee and ankle in all three planes of movement during initial contact, mid stance, toe off and mid swing events (Cont.)

Event	Joint	Action	Osteoarthritis Mean ± SD (n)	Controls Mean ± SD (n)
Mid stance	Hip	Flexion (+)	11.35 ± 4.70 (23)	7.25 ± 3.27 (21)
		Extension (-)	-2.41 (1)	-1.40 ± 1.58 (3)
		Adduction (+)	3.77 ± 2.15 (17)	4.32 ± 2.15 (24)
		Abduction (-)	-5.32 ± 3.45 (7)	-
		Internal (+)	7.065 ± 8.41 (8)	3.16 ± 2.19 (4)
		External rotation (-)	-14.54 ± 8.27 (16)	-5.14 ± 3.37 (20)
	Knee	Flexion (+)	11.14 ± 5.87 (21)	8.48 ± 3.49 (24)
		Extension (-)	-10.59 ± 13.41 (3)	-
		Varus (+)	7.19 ± 3.98 (20)	3.82 ± 3.12 (16)
		Valgus (-)	-1.47 ± 0.79 (4)	-1.43 ± 1.13 (8)
		Internal (+)	2.21 (1)	-
		External rotation (-)	-10.21 ± 8.52 (23)	-7.99 ± 4.74 (24)
	Ankle	Dorsiflexion (+)	12.68 ± 4.07 (23)	11.91 ± 3.28 (24)
		Plantarflexion (-)	-0.11 (1)	-
		Inversion (+)	2.75 ± 3.01 (7)	0.76 ± 0.84 (4)
		Eversion (-)	-4.15 ± 1.56 (17)	-3.68 ± 1.79 (20)
		Internal (+)	2.91 ± 2.49 (8)	1.35 ± 0.96 (5)
		External rotation (-)	-2.15 ± 2.85 (16)	-3.11 ± 2.26 (19)
Toe off	Hip	Flexion (+)	5.73 ± 3.50 (11)	5.06 ± 3.37 (6)
		Extension (-)	-6.07 ± 4.19 (13)	-6.38 ± 4.32 (18)
		Adduction (+)	0.71 (1)	2.19 (1)
		Abduction (-)	-6.37 ± 3.48 (23)	-5.74 ± 2.66 (23)
		Internal (+)	3.32 ± 1.91 (9)	6.83 ± 5.75 (6)
		External rotation (-)	-6.40 ± 3.33 (15)	-8.55 ± 6.08 (18)

Table 5.6 Number of participants showed the different trends of the angular displacement of hip, knee and ankle in all three planes of movement during initial contact, mid stance, toe off and mid swing events (Cont.)

Event	Joint	Action	Osteoarthritis Mean ± SD (n)	Controls Mean ± SD (n)
Toe off	Knee	Flexion (+)	36.09 ± 7.67 (24)	38.19 ± 3.35 (24)
		Extension (-)	-	-
		Varus (+)	8.94 ± 4.54 (15)	5.00 ± 5.00 (18)
		Valgus (-)	-6.94 ± 4.93 (9)	-6.54 ± 2.92 (6)
		Internal (+)	2.42 ± 2.85 (3)	4.47 (1)
		External rotation (-)	-10.95 ± 5.91 (21)	-10.44 ± 4.37 (23)
	Ankle	Dorsiflexion (+)	5.84 ± 4.12 (9)	-
		Plantarflexion (-)	-7.47 ± 4.98 (15)	-9.64 ± 5.14 (24)
		Inversion (+)	4.12 ± 2.44 (5)	1.39 ± 0.70 (3)
		Eversion (-)	-3.79 ± 2.33 (19)	-2.75 ± 1.66 (21)
		Internal (+)	1.73 ± 1.98 (15)	1.00 ± 2.42 (18)
		External rotation (-)	-1.38 ± 1.61 (9)	-1.88 ± 2.51 (6)
Mid swing	Hip	Flexion (+)	23.04 ± 5.32 (24)	23.58 ± 6.68 (24)
		Extension (-)	-	-
		Adduction (+)	2.44 ± 2.02 (2)	-
		Abduction (-)	-5.19 ± 3.37 (22)	-4.97 ± 2.37 (24)
		Internal (+)	8.34 ± 5.47 (10)	3.58 ± 2.10 (14)
		External rotation (-)	-10.19 ± 8.50 (14)	-5.35 ± 3.47 (10)
	Knee	Flexion (+)	55.58 ± 6.10 (24)	55.36 ± 3.99 (24)
		Extension (-)	-	-
		Varus (+)	8.85 ± 6.03 (17)	6.87 ± 4.06 (18)
		Valgus (-)	-8.71 ± 5.67 (7)	-5.87 ± 4.94 (6)
		Internal (+)	3.15 ± 1.78 (4)	2.63 ± 2.02 (4)
		External rotation (-)	-9.02 ± 5.86 (20)	-8.70 ± 3.45 (20)

Table 5.7 Number of participants showed the different trends of the angular displacement of hip, knee and ankle in all three planes of movement during initial contact, mid stance, toe off and mid swing events (Cont.)

Event	Joint	Action	Osteoarthritis Mean ± SD (n)	Controls Mean ± SD (n)
Mid swing	Ankle	Dorsiflexion (+)	7.55 ± 4.39 (24)	7.57 ± 2.58 (22)
		Plantarflexion (-)	-	-0.69 ± 0.34 (2)
		Inversion (+)	3.09 ± 3.38 (13)	2.19 ± 1.44 (10)
		Eversion (-)	-2.06 ± 1.27 (11)	-0.75 ± 0.81 (14)
		Internal (+)	3.49 ± 1.17 (6)	2.63 ± 2.33 (6)
		External rotation (-)	-8.36 ± 4.29 (18)	-7.20 ± 2.18 (18)

Figure 4.1 demonstrates the angular displacements of hip, knee, ankle in the coronal, sagittal and horizontal planes of participants with osteoarthritis and the control group. The osteoarthritis group showed significantly greater sagittal hip motion (flexion) and less coronal hip motion (adduction) than the control group at midstance phase (30% of the gait cycle). Significantly greater movement of knee joint in all three planes (flexion, varus, external rotation) was observed in the osteoarthritis group compared with the control group at initial contact phase (0% of the gait cycle). At approximately 30% gait cycle, the osteoarthritis group demonstrated a significantly higher degree of knee varus and knee external rotation than the control group. Lesser ankle motions were demonstrated in the sagittal plane (plantar flexion) at toe-off (60% of the gait cycle) and in the coronal plane (abduction) at initial contact (0% of the gait cycle) of the osteoarthritis group compared with the control group.

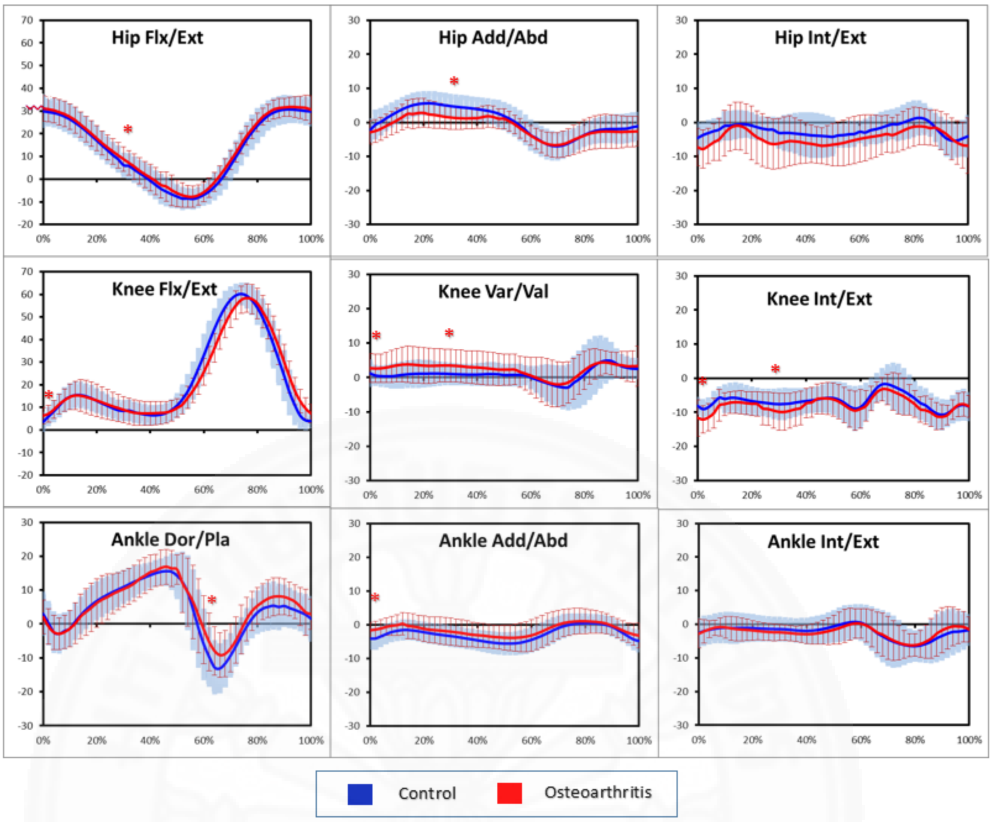

Figure 5.1 Angular displacements of hip, knee, ankle in the coronal, sagittal and horizontal planes of participants with osteoarthritis and the control group

Comparisons of angular displacements of hip, knee and ankle joints in sagittal, coronal and horizontal planes between participants with osteoarthritis and the control group at initial contact are shown in Table 4.4. The positive and negative signs represent the direction of motion corresponding to the plane of movement. At initial contact, there was a significant difference in angular displacement of knee joint in sagittal, coronal and horizontal planes and ankle joint in the coronal plane between participants with osteoarthritis and the control group. The results showed significant differences of knee joint angular displacements in participants with knee osteoarthritis comparing to the control group such as greater knee flexion, knee varus and knee external rotation and less ankle eversion.

Table 5.8 Comparisons of means and standard deviations of gait kinematics between participants with osteoarthritis and the control group at initial contact

Variables			Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Event	Joint	Action			
Initial contact	Hip	Flexion (+) / Extension (-)	31.86 ± 6.04	29.90 ± 6.17	0.272
		Adduction (+) / Abduction (-)	-3.07 ± 3.23	-2.29 ± 2.84	0.385
		Internal (+) / External rotation (-)	-7.80 ± 13.50	-4.61 ± 4.09	0.277
	Knee	Flexion (+) / Extension (-)	6.52 ± 6.02	3.62 ± 3.32	0.045*
		Varus (+) / Valgus (-)	4.79 ± 4.33	1.19 ± 3.25	0.002*
		Internal (+) / External rotation (-)	-12.64 ± 5.41	-8.32 ± 3.38	< 0.001*
	Ankle	Dorsiflexion (+) / Plantarflexion (-)	6.08 ± 5.54	5.23 ± 2.92	0.508
		Inversion (+) / Eversion (-)	-1.98 ± 4.03	-4.04 ± 2.38	0.038*
		Internal (+) / External rotation (-)	-2.80 ± 3.35	-2.06 ± 3.12	0.783

Note: *= Significant difference at p-value < 0.05

Comparisons of angular displacements of hip, knee and ankle joints in sagittal, coronal and horizontal planes between participants with osteoarthritis and the control group at mid stance are shown in Table 4.5. At mid stance, there was a significant difference in angular displacement of hip joint in sagittal and coronal planes and knee joint in coronal and horizontal planes between participants with osteoarthritis and the control group. The results showed significant differences of hip joint angular displacements in participants with knee osteoarthritis comparing to the control such as greater hip flexion, knee varus and knee external rotation and less hip adduction.

Table 5.9 Comparisons of means and standard deviations of gait kinematics between participants with osteoarthritis and the control group at mid stance

Variables			Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Event	**Joint**	**Action**			
Mid stance	Hip	Flexion (+) / Extension (-)	10.78 ± 5.39	6.17 ± 4.25	0.002*
		Adduction (+) / Abduction (-)	1.11 ± 4.91	4.32 ± 2.15	0.019*
		Internal (+) / External rotation (-)	-7.14 ± 13.43	-3.76 ± 4.66	0.254
	Knee	Flexion (+) / Extension (-)	8.42 ± 9.98	8.48 ± 3.49	0.509
		Varus (+) / Valgus (-)	5.75 ± 4.90	2.06 ± 3.63	0.005*
		Internal (+) / External rotation (-)	-10.44 ± 9.14	-7.99 ± 4.74	0.041*
	Ankle	Dorsiflexion (+) / Plantarflexion (-)	12.15 ± 4.76	11.91 ± 3.28	0.839
		Inversion (+) / Eversion (-)	-2.14 ± 3.78	-2.94 ± 2.36	0.773
		Internal (+) / External rotation (-)	-2.38 ± 3.49	-1.43 ± 3.12	0.668

Note: *= Significant difference at p-value < 0.05

Comparisons of angular displacements of hip, knee and ankle joints in sagittal, coronal and horizontal planes between participants with osteoarthritis and control group at toe off are shown in Table 4.6. At toe off, there was a significant difference in angular displacement of ankle joint in the sagittal plane between participants with osteoarthritis and the control group. The results showed significant differences of ankle joint angular displacements in participants with knee osteoarthritis comparing to the control. Less ankle plantarflexion was found in the osteoarthritis group.

Table 5.10 Comparisons of means and standard deviations of gait kinematics between participants with osteoarthritis and the control group at toe off

Variables			Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Event	Joint	Action			
Toe off	Hip	Flexion (+) / Extension (-)	-2.66 ± 7.11	-3.52 ± 6.47	0.152
		Adduction (+) / Abduction (-)	-6.08 ± 3.69	-5.41 ± 3.06	0.498
		Internal (+) / External rotation (-)	-2.75 ± 5.58	-4.70 ± 8.99	0.372
	Knee	Flexion (+) / Extension (-)	36.09 ± 7.67	38.19 ± 3.35	0.229
		Varus (+) / Valgus (-)	2.98 ± 9.09	2.11 ± 6.81	0.710
		Internal (+) / External rotation (-)	-9.28 ± 7.17	-9.95 ± 4.91	0.196
	Ankle	Dorsiflexion (+) / Plantarflexion (-)	-2.48 ± 8.02	-9.64 ± 5.14	0.001*
		Inversion (+) / Eversion (-)	--2.14 ± 4.00	-2.23 ± 2.10	0.925
		Internal (+) / External rotation (-)	0.17 ± 4.65	0.45 ± 4.22	0.785

Note: *= Significant difference at p-value < 0.05

Comparisons of angular displacements of hip, knee and ankle joints in sagittal, coronal and horizontal planes between participants with osteoarthritis and control group at mid swing are shown in Table 4.7. In swing period, there were no significant differences between groups in mean values of angular displacement of hip, knee and ankle joints at mid swing.

Table 5.11 Comparisons of means and standard deviations of gait kinematics between participants with osteoarthritis and the control group at mid swing

Variables			Osteoarthritis (n=24)	Controls (n=24)	*p*-value
Event	Joint	Action			
Mid swing	Hip	Flexion (+) / Extension (-)	23.04 ± 5.32	23.58 ± 6.68	0.758
		Adduction (+) / Abduction (-)	-4.55 ± 3.90	-4.97 ± 2.37	0.726
		Internal (+) / External rotation (-)	-2.47 ± 11.82	-0.13 ± 5.24	0.383
	Knee	Flexion (+) / Extension (-)	55.58 ± 6.10	55.36 ± 3.90	0.880
		Varus (+) / Valgus (-)	3.27 ± 10.01	3.69 ± 7.02	0.853
		Internal (+) / External rotation (-)	-6.99 ± 7.09	-6.81 ± 5.38	0.921
	Ankle	Dorsiflexion (+) / Plantarflexion (-)	7.55 ± 4.9	6.88 ± 3.40	0.853
		Inversion (+) / Eversion (-)	0.73 ± 3.68	0.47 ± 1.84	0.635
		Internal (+) / External rotation (-)	-6.20 ± 4.12	-6.48 ± 4.53	0.742

Note: *= Significant difference at p-value < 0.05

4.3 Correlations between gait characteristics (spatiotemporal variables and gait kinematics) and history of falls in participants with osteoarthritis

Table 4.8 shows the correlation between the spatiotemporal gait and the number of falls in previous 12 months in participants with osteoarthritis. There was no correlation between the spatiotemporal gait and number of falls in previous 12 months.

Table 5.12 Correlations between the spatiotemporal gait and number of falls in previous 12 months in participants with osteoarthritis

Variables	Number of falls in previous 12 months
Velocity (m/sec)	-0.303
Cadence (step/min)	-0.232
Step time (sec)	0.296
Step length (m)	-0.240
Stride time (sec)	0.249
Stride length (m)	-0.286
Single support time (% cycle)	-0.229
Double support time (% cycle)	0.243

Table 4.9 shows the correlation between gait kinematics and the number of falls in previous 12 months in participants with osteoarthritis. There was no correlation between gait kinematics and number of falls in previous 12 months.

Table 5.13 Correlations between gait kinematics and the number of falls in previous 12 months in participants with osteoarthritis

Variables			Number of falls in previous 12 months
Event	**Joint**	**Action**	
Initial contact	Knee	Flexion (+) / Extension (-)	-0.136
		Varus (+) / Valgus (-)	0.286
		Internal (+) / External rotation (-)	-0.256
	Ankle	Inversion (+) / Eversion (-)	0.045
Mid stance	Hip	Flexion (+) / Extension (-)	0.196
		Adduction (+) / Abduction (-)	-0.316
	Knee	Varus (+) / Valgus (-)	0.226
		Internal (+) / External rotation (-)	-0.136
Toe off	Ankle	Dorsiflexion (+) / Plantarflexion (-)	0.196

Table 4.10 shows the correlation between gait kinematics and the Modified Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and clinical measures in participants with osteoarthritis. There was significant correlation between angular displacement of the knee joint in transverse plane and knee extension force (r = 0.414) at initial contact**.** The osteoarthritis group also showed significant correlation between angular displacement of the ankle joint in the sagittal plane and knee joint position sense (r = 0.482) at toe off. However, no correlation was found between the modified WOMAC and mean values of the hip, knee and ankle angular displacement at all events**.**

Table 5.14 Correlations between gait kinematics and the Modified Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and clinical measures in participants with osteoarthritis

Variables			**Modified WOMAC**				**Knee joint position sense**	**Knee extension force**
Event	**Joint**	**Action**	**Pain**	**Stiffness**	**Function**	**Total**		
Initial contact	Knee	Flexion (+) / Extension (-)	-0.371	0.137	0.123	-0.088	-0.110	0.323
		Varus (+) / Valgus (-)	-0.093	-0.026	-0.172	-0.127	-0.162	0.079
		Internal (+) / External rotation (-)	-0.047	-0.088	-0.217	-0.060	0.271	0.414*
	Ankle	Inversion (+) / Eversion (-)	0.097	-0.300	0.042	-0.038	0.361	0.208
Mid stance	Hip	Flexion (+) / Extension (-)	0.110	0.314	0.343	0.264	0.037	-0.080
		Adduction (+) / Abduction (-)	0.348	0.136	0.199	0.250	0.395	-0.148

Table 5.15 Correlations between gait kinematics and the Modified Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and clinical measures in participants with osteoarthritis (Cont.)

Variables			Modified WOMAC				Knee joint position sense	Knee extension force
Event	**Joint**	**Action**	**Pain**	**Stiffness**	**Function**	**Total**		
Mid stance	Knee	Varus (+) / Valgus (-)	-0.098	-0.044	-0.126	-0.099	-0.356	-0.078
		Internal (+) / External rotation (-)	-0.051	0.019	-0.127	-0.147	0.131	0.152
Toe off	Ankle	Dorsiflexion (+) / Plantarflexion (-)	0.296	0.062	0.290	0.344	0.482*	-0.047

Note: *= Significant difference at p-value < 0.05

CHAPTER 5
DISCUSSION

The discussion is divided into three sections: participant characteristics, comparison of gait characteristics (spatiotemporal variables and gait kinematics) between the participants with knee osteoarthritis and the control group, and correlations between gait characteristics and history of falls in participants with knee osteoarthritis.

5.1 Participant characteristics

Participants in this study were 48 older people with and without knee osteoarthritis age ranged 60-84 years. There were no significant differences in mean age, weight, height and BMI between the participants with knee osteoarthritis and the control group. Therefore, the factors of age, weight, height and BMI would not affect the gait characteristics between groups in this study.

The error angle in this study was calculated from the difference between values of measurement angle and reference angle in each trial tested. The finding of knee joint position sense in the knee osteoarthritis group compared with the control group in this study was represented with the mean absolute angular error which were 8.61 and 2.41 degrees, respectively. Several studies [89, 155, 156, 157] reported the impairment of proprioception in osteoarthritis patients. It was reported that proprioceptive information was received from joints and muscles by the receptors within knee joint ligaments, meniscus, tendon, capsules and muscles surrounding the knee [158]. Sharma and Pai [156] reviewed the concepts of impaired proprioception in osteoarthritis knee. They suggested that proprioceptive impairment may result from osteoarthritis pathology which destroys the function of capsule, ligament or muscle-tendon mechanoreceptors. Besides, the decline in proprioception in older people may also lead to an increase in poor load distributed and cause osteoarthritis.

In term of knee muscle strength, our findings showed significant lower strength in knee extensor muscle in the knee osteoarthritis group compared with the control group. There are controversies regarding the cause of weakness in the knee osteoarthritis group. Sharma and colleagues [160] suggested that muscle strength was correlated with physical function. Therefore, muscle weakness could be a risk factor for pain in osteoarthritis.

5.2 Comparison of gait characteristics (spatiotemporal variables and gait kinematics) between the participants with knee osteoarthritis and the control group

5.2.1 Spatiotemporal variables

Spatiotemporal variables and angular displacement of the knee are the important gait parameters in knee osteoarthritis [96]. Comparison between the knee osteoarthritis group and the control group, there were significant differences in velocity, cadence, step length, stride length, step time, stride time, single support time and double support time at preferred gait speed. Similar to several previous studies [161, 162, 163], the knee osteoarthritis group showed decrease in velocity, cadence, step length, single support time and stride length and increase in step time, stride time and double support time when comparing to the control group. Comparison between the knee osteoarthritis group and the control group in this study found that the knee osteoarthritis group had a shorter stride length and lower cadence that likely contributed to lower gait speed. Previous study[165] also found that the knee osteoarthritis group walked slower than the control group. Stauffer and colleagues [166] reported lower cadence in the knee osteoarthritis group. Gait speed of the knee osteoarthritis group in this study was slower than the control group. It can be explained by pain avoidance mechanism on the painful limb during single limb support and shorter stance duration on the painful limb in the knee osteoarthritis group. A few studies [164, 165] also reported longer stance time in the knee osteoarthritis group compared to the control group which attributed to a longer double support time. According to these group of researchers[166], increasing double support time and reducing gait speed are pain relief strategies to reduce the compressive load on the knee joint. Therefore, the knee osteoarthritis group will rapidly shift weight to another limb to reduce the pain during walking, which will lead to shorter durations of single limb support.

5.2.2 Gait kinematics

Comparison of angular displacements between the two groups, this study found some significant differences at the gait events of initial contact, mid stance and toe off. The reasons for the differences are discussed in the following sessions. A few studies reported decreased the range of motion of the knee joint and increased the range of motion of other joints of the lower extremities in the knee osteoarthritis group [167, 168].

In initial contact, there were some significant differences of knee and ankle joints in coronal, sagittal and horizontal planes between the knee osteoarthritis and the control groups. In this study, the greater knee flexion found in the osteoarthritis group was possibly due to a compensation aiming to increase knee stability and to decrease pain by shifting the center of mass laterally to unload the knee joint. The results of this study were similar to the previous studies [121, 142, 169]. These finding are in contrast with a study of moderate and severe knee osteoarthritis [121, 141] revealing that the severe knee osteoarthritis group used a knee stiffening strategy and higher muscle co-contraction to stabilize and control the knee joint. Higher co-contraction could lead to decreased knee motion during initial contact. Briem and Snyder-Mackler [170], performed a study in 32 patients with moderate knee osteoarthritis.

The results of this study revealed that the knee osteoarthritis group showed a significant greater knee varus angle (adduction). These data are consistent with the findings of previous studies [141, 170, 171, 172]. Takashi and colleagues [173] reported varus alignment of the knee joint in the knee osteoarthritis group, the center of pressure run along inside of the knee rather than center of the knee during heel contact the ground, the moment from the floor that acts to create knee varus alingment.

In this study, knee external rotation in the knee osteoarthritis group was significantly greater than the control group. The similar result was observed in a study by Nagano [141]. This difference at this gait phase which corresponds to maximal knee extension, might due to the lack of full extension of the osteoarthritis knees [174]. Additionally, the external rotation of the tibia in the osteoarthritis group has been previously proposed as a compensatory strategy to decrease knee joint loading over the commonly damaged central and anterior regions of the medial knee compartment [171].

In midstance, there were some significant differences of hip and knee joint in all three planes of movement between the knee osteoarthritis and the control groups. Greater knee varus (adduction) in the osteoarthritis group was presented and the angle was higher than during the initial contact phase. These data are consistent with the findings of previous studies [141, 171, 172]. The explanation could be that possibility the knee varus angle in the osteoarthritis group could be greatly observed with high loading on the medial compartment during single limb support Nagano and colleagues [141] revealed that the knee adduction angle at the 60% stance phase was significantly greater in the participants with moderate and severe knee osteoarthritis than in the control group. During single limb support, the ROM of knee osteoarthritis subjects may present genu varus deformity with the high loading within the medial compartment [141, 170]**.** This deviation of knee motion might result in the lack of normal hip extension seen as greater hip flexion in the osteoarthritis group compared with the control in this study. Murray and colleagues [174] reported that gait abnormalities usually related to abnormal knee motion during stance in which might lead to the lack of a normal hip extension on the painful side.

In toe off, decreased ankle plantar flexion found in the osteoarthritis group was possibly due to a compensation aiming to decrease compressive knee joint reaction forces by using the hip flexors rather than the ankle plantar flexors to propel the lower limb. Matthew and colleagues [175] revealed a significant decreased the ankle plantar flexor moments during toe off. The participants with knee osteoarthritis reduced plantar flexor moments may be an attempt to decrease the forces at the knee joint. During normal walking, ankle plantar flexor moments may increase the forces at the knee joint when restraining the forward motion of the tibia on the talus [176].

In mid swing, there were no significant differences of hip and knee joint in all three planes of movement between the knee osteoarthritis and the control groups. This results possibly support that knee osteoarthritis unlikely to affect range of hip, knee, and ankle joint movement during non-weight bearing phase of gait.

5.3 Correlations between gait characteristics (spatiotemporal variables and gait kinematics), history of falls and impairments in participants with knee osteoarthritis

Due to the limited number of participants with knee osteoarthritis had fallen, we could not find any correlation between gait characteristics (spatiotemporal variables and gait kinematics) and history of falls. The explanation of no correlation between mean values of kinematic gait variables and history of falls possibly due to the average between the positive and negative angle. The use of average between positive and negative angle which is not an actual angle may reduce the association of gait characteristics and history of falls or impairments. Another possible reason could be the fact that our participants had only mild to moderate severity of knee osteoarthritis which could be seen from slightly low WOMAC score. Another explanation could be the possibility that the participants with knee osteoarthritis may have higher concern/ awareness of movement or doing physical activities compared with participants without knee osteoarthritis. We could not really confirm this hypothesis as this study did not assess level of physical activity. However, we might be able to assume that the group of participants with knee osteoarthritis may possibly limit their physical activities from the results of the study which found that the knee osteoarthritis group has less muscle strength than the control group.

It is interesting to note that in the present study, most of the significant differences were detected in the coronal and horizontal planes. This means that if 2D gait analysis system was used in this study, some significant differences between right and left lower extremities would not be detected. This may lead to misinterpretation of the results. Therefore, the 3D gait analysis system is important to detect the out of plane movement particularly the pathologic gait.

5.4 Limitation

This study included participants with relatively mild to moderate severity knee osteoarthritis in which different from a previous study by Astephen and co-workers [121] which compared osteoarthritis groups with different severities with the control group. The study reported that the moderate and severe osteoarthritis groups had a significantly smaller knee flexion angle than the control group ($p<0.05$). Sample size of the previous study was larger and greater severity levels.

Finally, there could be possibility of errors in the placement of the reflective markers for gait analysis in this study. Excess adipose tissue as seen in obese participants made it difficult to locate the correct bony landmarks for marker placement. However, in participants those who are obese or was found to be difficult to exactly place the markers on the ASIS, or invisible of markers in this position to cameras; each marker was moved laterally by an equal amount along the ASIS-ASIS axis to minimize surface (skin) motion. In addition, the true inter-ASIS distance was then be recorded and entered as the subject parameters in the Vicon program.

5.5 Clinical implications

The spatiotemporal characteristics and patterns of kinematics during walking could be used as parameters to evaluate and reevaluate the patients with knee problems. The parameters of spatiotemporal characteristics including velocity, cadence, stride time, stride length, step time, step length, single support time and double support time have been useful to evaluate the impairment of patients after treatment.

The deviation in kinematic patterns which happened in the knee osteoarthritis patients would lead to more better understanding of the compensatory mechanism of lower extremities. Moreover, other factors which involve in this deviation could be revealed, such as the effect of muscle strength around the affected joint. The quantitative gait analysis is important to investigate the kinematic gait characteristics. The better knowledge obtained from this gait analysis will bring to the improvement for diagnosis, assessment and prognosis in knee osteoarthritis patients.

5.6 Further study

Therefore, further studies utilizing large sample size with varying degrees of severity of knee osteoarthritis may provide valuable insight into characterizing gait changes in response to osteoarthritis. In addition, assessment should include evaluating the level of physical activity or exercise that was performed as part of leisure and occupation.

CHAPTER 6
CONCLUSIONS

This study compared gait characteristics (spatiotemporal variables and gait kinematics) between the participants with knee osteoarthritis group and the control group. In addition, correlations between gait characteristics and history of falls in participants with knee osteoarthritis were determined.

6.1 Comparison of gait characteristics (spatiotemporal variables and gait kinematics) between the participants with knee osteoarthritis and the control group

Participants with knee osteoarthritis adopt different compensatory biomechanical strategies while walking. The knee osteoarthritis group walked with slower walking velocity, less cadence, shorter step length, longer single support time and shorter stride length than the control group. There were significant higher step time, stride time and double support time when comparing to the control group.

Gait kinematics changes among older people with mild to severe knee osteoarthritis could be detected through 3D gait analysis. Knee osteoarthritis influenced gait kinematics involving not only knee joint but also hip and ankle joint movement.

6.2 Correlations between gait characteristics and history of falls in participants with knee osteoarthritis

There were no correlation between gait characteristics (spatiotemporal variables and gait kinematics) and history of falls in older people with mild severity of osteoarthritis knee. It is postulated that participants with osteoarthritis symptoms may have awareness of the presence and careful in their physical activity or perhaps restricted their activities of daily living. It should also be noted that the current study is retrospective and older participants may possibly underestimate or overestimate their falling history.

REFERENCES

1. Perry J, Burnfield JM. Gait analysis: normal and pathological function. Slack Incorporated; 1992.
2. Hsu RW, Himeno S, Coventry MB, Chao EY. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. Clin Orthop Relat Res. 1990(255):215-27.
3. World Population Aging 2015 [Internet]. United Nations, department of economic and social affairs, Population Division. 2015 [cited 2016 October]. Available from: http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf.
4. Situation of the thai elderly 2013 [Internet]. Foundation of Thai Gerontology Research and Development institute. 2013 [cited 2016 October]. Available from: http://thaitgri.org/?p=37134.
5. Carey D, Laffoy M. Hospitalisations due to falls in older persons. Ir Med J. 2005;98(6):179-81.
6. Watson WL, Mitchell R. Conflicting trends in fall-related injury hospitalisations among older people: variations by injury type. Osteoporos Int. 2011;22(10):2623-31.
7. American Geriatrics Society; British Geriatrics Society. Guideline for the prevention of falls in older persons. J Am Geriatr Soc. 2001;49(5):664-72.
8. Blake A, Morgan K, Bendall M, Dallosso H, Ebrahim S, Arie T, et al. Falls by elderly people at home: prevalence and associated factors. Age Ageing. 1988;17(6):365-72.
9. Lawlor DA, Patel R, Ebrahim S. Association between falls in elderly women and chronic diseases and drug use: cross sectional study. BMJ. 2003;327:712-7.
10. Lawrence RC, Felson DT, Helmick CG, Arnold LM, Choi H, Deyo RA, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States: Part II. Arthritis Rheum. 2008;58(1):26-35.
11. Kelsey JL, Berry SD, Procter E, Quach L. Indoor and outdoor falls in older adults are different: the maintenance of balance, independent living, intellect, and zest in the elderly of Boston study. J Am Geriatr Soc. 2010;58(11):2135-41.

12. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community based prospective study of people 70 years and older. J Gerontol. 1989;44(5):M112-7.
13. Rubenstein LZ, Robbins AS, Schulman BL, Rosado J, Osterweil D, Josephson KR. Falls and instability in the elderly. J Am Geriatr Soc. 1988;36(3):266-78.
14. Quach L, Galica AM, Jones RN, Procter E, Manor B, Hannan MT, et al. The nonlinear relationship between gait speed and falls: the maintenance of balance, independent living, intellect, and zest in the elderly of Boston study. J Am Geriatr Soc. 2011;59(6):1069-73.
15. Lipsitz LA, Jonsson PV, Kelley MM, Koestner JS. Causes and correlates of recurrent falls in ambulatory frail elderly. J Gerontol. 1991;46(4):M114-M22.
16. Guimaraes R, Isaacs B. Characteristics of the gait in old people who fall. Int Rehabil Med. 1980;2(4):177-80.
17. Ng CT, Tan MP. Osteoarthritis and falls in the older person. Age Ageing. 2013;42(5):561-6.
18. Kiss RM. Effect of severity of knee osteoarthritis on the variability of gait parameters. J Electromyogr Kinesiol. 2011;21(5):695-703.
19. Lamb SE, Jørstad EC, Hauer K, Becker C. Development of a common outcome data set for fall injury prevention trials. J Am Geriatr Soc. 2005;53(9):1618-22.
20. Lord SR, Ward JA, Williams P, Anstey KJ. An epidemiological study of falls in older community dwelling women: the Randwick falls and fractures study. Aust J Public Health. 1993;17(3):240-5.
21. Prudham D, Evans JG. Factors associated with falls in the elderly: a community study. Age Ageing. 1981;10(3):141-6.
22. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med. 1988;319(26):1701-7.
23. Downton J, Andrews K. Prevalence, characteristics and factors associated with falls among the elderly living at home. Aging Clin Exp Res. 1991;3(3):219-28.
24. Tinetti ME. Factors associated with serious injury during falls by ambulatory nursing home residents. J Am Geriatr Soc. 1987;35(7):644-8.
25. Kang HG, Costa MD, Priplata AA, Starobinets OV, Goldberger AL. Frailty and the degradation of complex balance dynamics during a dual-task protocol. J Gerontol. 2009;64(12):1304-11.

26. Kannus P, Sievänen H, Palvanen M, Järvinen T, Parkkari J. Prevention of falls and consequent injuries in elderly people. Lancet. 2005;366(9500):1885-93.
27. Campbell AJ, Borrie MJ, Spears GF. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing. 1990;19(2):136-41.
28. Fletcher PC, Hirdes JP. Restriction in activity associated with fear of falling among community-based seniors using home care services. Age Ageing. 2004;33(3):273-9.
29. Bohl AA, Fishman PA, Ciol MA, Williams B, Phelan EA. A longitudinal analysis of total 3-year healthcare costs for older adults who experience a fall requiring medical care. J Am Geriatr Soc. 2010;58(5):853-60.
30. Delaune M, Ciolek C. Falls in community dwelling older adults: preventing falls and fall-related injuries addresses both evaluations and tests and interventions 2007.
31. Fuller GF. Falls in the elderly. Am Fam Physician. 2000;61(7):2159-68, 73-4.
32. Hosseini H, Hosseini N. Epidemiology and prevention of fall injuries among the elderly. Hosp Top. 2008;86(3):15-20.
33. Petridou ET, Manti EG, Ntinapogias AG, Negri E, Szczerbińska K. What works better for community-dwelling older people at risk to fall?: a meta-analysis of multifactorial versus physical exercise-alone interventions. J Aging Health. 2009;21(5):713-29.
34. Moreland JD, Richardson JA, Goldsmith CH, Clase CM. Muscle weakness and falls in older adults: a systematic review and meta-analysis. J Am Geriatr Soc. 2004;52(7):1121-9.
35. Cooper JW, Burfield AH. Medication interventions for fall prevention in the older adult. J Am Pharm Assoc. 2009;49(3):e70-e84.
36. Wiener JM, Hanley RJ, Clark R, Van JF. Measuring the activities of daily living: Comparisons across national surveys. J Gerontol. 1990;45(6):S229-S37.
37. Lawrence RC, Helmick CG, Arnett FC, Deyo RA, Felson DT, Giannini EH, et al. Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. Arthritis Rheum. 1998;41(5):778-99.
38. Arnett FC, Edworthy SM, Bloch DA, Mcshane DJ, Fries JF, Cooper NS, et al. The American Rheumatism Association 1987 revised criteria for the classification of rheumatoid arthritis. Arthritis Rheum. 1988;31(3):315-24.

39. Ickinger C, Tikly M. Current approach to diagnosis and management of osteoarthritis. SA Fam Pract. 2014;56(2):102-8.
40. Kuptniratsaikul V, Tosayanonda O, Nilganuwong S, Thamalikitkul V. The epidemiology of osteoarthritis of the knee in elderly patients living an urban area of Bangkok. J Med Assoc Thai. 2002;85(2):154-61.
41. Litwic A, Edwards MH, Dennison EM, Cooper C. Epidemiology and burden of osteoarthritis. Br Med Bull. 2013;105:185-99.
42. Conaghan P. Update on osteoarthritis part 1: current concepts and the relation to exercise. Br J Sports Med. 2002;36(5):330-3.
43. Mcalindon TE, Wilson PW, Aliabadi P, Weissman B, Felson DT. Level of physical activity and the risk of radiographic and symptomatic knee osteoarthritis in the elderly: the Framingham study. Am J Med. 1999;106(2):151-7.
44. Gelber AC, Hochberg MC, Mead LA, Wang N, Wigley FM, Klag MJ. Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. Ann Intern Med. 2000;133(5):321-8.
45. Garstang SV, Stitik TP. Osteoarthritis: epidemiology, risk factors, and pathophysiology. Am J Phys Med Rehabil. 2006;85(11):S2-S11.
46. Lopez AD, Murray CJ. Measuring the global burden of disease. N Engl J Med 2013;369:448-57.
47. Woolf AD, Pfleger B. Burden of major musculoskeletal conditions. Bulletin of the World Health Organization. 2003;81(9):646-56.
48. Klippel JH, Stone JH, White PH. Primer on the rheumatic diseases. 9th, editor. United State: Arthritis Foundation; 2008.
49. Hutton C. Osteoarthritis: the cause not result of joint failure? Ann Rheum Dis. 1989;48(11):958-61.
50. Arden N, Nevitt MC. Osteoarthritis: epidemiology. Best Pract Res Clin Rheumatol. 2006;20(1):3-25.
51. Felson DT. Osteoarthritis of the knee. N Engl J Med. 2006;354(8):841-8.
52. Zedka M, Prochazka A, Knight B, Gillard D, Gauthier M. Voluntary and reflex control of human back muscles during induced pain. J Physiol. 1999;520(2):591-604.

53. Weiler H, Pap G, Awiszus F. The role of joint afferents in sensory processing in osteoarthritic knees. Rheumatology. 2000;39(8):850-6.
54. Hurley MV, Scott DL, Rees J, Newham DJ. Sensorimotor changes and functional performance in patients with knee osteoarthritis. Ann Rheum Dis. 1997;56(11):641-8.
55. Franchi A, Zaccherotti G, Aglietti P. Neural system of the human posterior cruciate ligament in osteoarthritis. J Arthroplasty. 1995;10(5):679-82.
56. Proske U, Wise A, Gregory J. The role of muscle receptors in the detection of movements. Prog Neurobiol. 2000;60(1):85-96.
57. Bennell K, Hinman R. Exercise as a treatment for osteoarthritis. Curr Opin Rheumatol. 2005;17(5):634-40.
58. Felson DT, Niu J, Mcclennan C, Sack B, Aliabadi P, Hunter DJ, et al. Knee buckling: prevalence, risk factors, and associated limitations in function. Ann Intern Med. 2007;147(8):534-40.
59. Fitzgerald GK, Piva SR, Irrgang JJ. Reports of joint instability in knee osteoarthritis: its prevalence and relationship to physical function. Arthritis Rheum. 2004;51(6):941-6.
60. Ramsey DK, Snyder L, Lewek M, Newcomb W, Rudolph KS. Effect of anatomic realignment on muscle function during gait in patients with medial compartment knee osteoarthritis. Arthritis Rheum. 2007;57(3):389-97.
61. Lewek MD, Ramsey DK, Snyder L, Rudolph KS. Knee stabilization in patients with medial compartment knee osteoarthritis. Arthritis Rheum. 2005;52(9):2845-53.
62. Schmitt LC, Fitzgerald GK, Reisman AS, Rudolph KS. Instability, laxity, and physical function in patients with medial knee osteoarthritis. Phys Ther. 2008;88(12):1506-16.
63. Bennell KL, Hunt MA, Wrigley TV, Lim B, Hinman RS. Role of muscle in the genesis and management of knee osteoarthritis. Rheum Dis Clin North Am. 2008;34(3):731-54.
64. Hubley C, Deluzio K, Landry S, Mcnutt J, Stanish W. Neuromuscular alterations during walking in persons with moderate knee osteoarthritis. J Electromyogr Kinesiol. 2006;16(4):365-78.

65. Jackson B, Wluka A, Teichtahl A, Morris M, Cicuttini F. Reviewing knee osteoarthritis: a biomechanical perspective. J Sci Med Sport. 2004;7(3):347-57.

66. Rutherford DJ, Hubley CL, Stanish WD, Dunbar MJ. Neuromuscular alterations exist with knee osteoarthritis presence and severity despite walking velocity similarities. Clin Biomech. 2011;26(4):377-83.

67. Schipplein O, Andriacchi T. Interaction between active and passive knee stabilizers during level walking. J Orthop Res. 1991;9(1):113-9.

68. Segal NA, Glass NA, Felson DT, Hurley M, Yang M, Nevitt M, et al. The effect of quadriceps strength and proprioception on risk for knee osteoarthritis. Med Sci Sports Exerc. 2010;42(11):2081.

69. Fisher N, Pendergast D. Reduced muscle function in patients with osteoarthritis. Scand J Rehabil Med. 1997;29(4):213-21.

70. Hassan B, Mockett S, Doherty M. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Ann Rheum Dis. 2001;60(6):612-8.

71. Felson DT. Risk factors for osteoarthritis: understanding joint vulnerability. Clin Orthop Relat Res. 2004;427:S16-S21.

72. Uhlig T, Slatkowsky B, Moe RH, Kvien TK. The burden of osteoarthritis: the societal and the patient perspective. Therapy. 2010;7(6):605-19.

73. Robert WW SC, Mark B. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. Clin Orthop Relat Res. 1990;255:215-27.

74. Brouwer G, Van A, Bergink A, Belo J, Bernsen R, Reijman M. Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. Arthritis Rheum. 2007;56(4):1204-11.

75. Sharma L, Song J, Felson DT, Shamiyeh E, Dunlop DD. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA. 2001;286(2):188-95.

76. Sharma L, Hurwitz DE, Thonar E, Sum JA, Lenz ME, Dunlop DD. Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. Arthritis Rheum. 1998;4:13.

77. Miyazaki T, Wada M, Kawahara H, Sato M, Baba H, Shimada S. Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. Ann Rheum Dis. 2002;61(7):617-22.
78. Thomas RH, Resnick D, Alazraki NP, Daniel D, Greenfield R. Compartmental evaluation of osteoarthritis of the knee: a comparative study of available diagnostic modalities. Radiology. 1975;116(3):585-94.
79. Felson DT, Zhang Y, Hannan MT, Naimark A, Weissman B, Aliabadi P, et al. Risk factors for incident radiographic knee osteoarthritis in the elderly. Arthritis Rheum. 1997;40(4):728-33.
80. Manninen P, Riihimäki H, Heliövaara M, Mäkelä P. Overweight, gender and knee osteoarthritis. Int J Obes Relat Metab Disord. 1996;20(6):595-7.
81. Dougados M, Gueguen A, Nguyen M, Thiesce A, Listrat V, Jacob L, et al. Longitudinal radiologic evaluation of osteoarthritis of the knee. J Rheumatol. 1992;19(3):378-84.
82. Schouten J, Van F, Valkenburg H. A 12 year follow up study in the general population on prognostic factors of cartilage loss in osteoarthritis of the knee. Ann Rheum Dis. 1992;51(8):932-7.
83. Hoops ML, Rosenblatt NJ, Hurt CP, Crenshaw J, Grabiner MD. Does lower extremity osteoarthritis exacerbate risk factors for falls in older adults? Womens Health. 2012;8(6):685-98.
84. Knoop J, Leeden M, Esch M, Thorstensson CA, Gerritsen M, Voorneman RE, et al. Association of lower muscle strength with self-reported knee instability in osteoarthritis of the knee: results from the Amsterdam osteoarthritis cohort. Arthritis Rheum. 2012;64(1):38-45.
85. Sturnieks DL, Tiedemann A, Chapman K, Munro B, Murray SM, Lord SR. Physiological risk factors for falls in older people with lower limb arthritis. J Rheumatol. 2004;31(11):2272-9.
86. Knoop J, Steultjens M, Leeden M, Esch M, Thorstensson C, Roorda L, et al. Proprioception in knee osteoarthritis: a narrative review. Osteoarthritis Cartilage. 2011;19(4):381-8.
87. Bascuas I, Tejero M, Monleón S, Boza R, Muniesa JM, Belmonte R. Balance 1 year after TKA: correlation with clinical variables. Orthopedics. 2013;36(1):e6-e12.

88. Wegener L, Kisner C, Nichols D. Static and dynamic balance responses in persons with bilateral knee osteoarthritis. J Orthop Sports Phys Ther. 1997;25(1):13-8.

89. Sharma L, Pai C, Holtkamp K, Rymer WZ. Is knee joint proprioception worse in the arthritic knee versus the unaffected knee in unilateral knee osteoarthritis? Arthritis Rheum. 1997;40(8):1518-25.

90. Woollacott M, Shumway A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture. 2002;16(1):1-14.

91. Hsieh RL, Lee WC, Lo MT, Liao WC. Postural stability in patients with knee osteoarthritis: comparison with controls and evaluation of relationships between postural stability scores and international classification of functioning, disability and health components. Arch Phys Med Rehabil. 2013;94(2):340-6. e1.

92. Hinman R, Bennell K, Metcalf B, Crossley K. Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. Rheumatology. 2002;41(12):1388-94.

93. Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med. 2002;18(2):141-58.

94. Whittle MW. Gait analysis: an introduction. 3rd, editor. Boston: Butterworth Heinemann; 2002.

95. Kirtley C. Clinical gait analysis: theory and practice. Edinburgh: Elsevier Health Sciences; 2006.

96. Györy AN, Chao E, Stauffer RN. Functional evaluation of normal and pathologic knees during gait. Arch Phys Med Rehabil. 1976;57(12):571-7.

97. Baker R. Gait analysis methods in rehabilitation. J Neuroengineering Rehabil. 2006;3(1):1.

98. Mcginley JL, Baker R, Wolfe R, Morris ME. The reliability of three-dimensional kinematic gait measurements: a systematic review. Gait Posture. 2009;29(3):360-9.

99. Benabdelkader C, Cutler RG, Davis LS. Gait recognition using image self-similarity. J Adv Signal Process. 2004;2004(4):1-14.

100. Faude O, Donath L, Roth R, Fricker L, Zahner L. Reliability of gait parameters during treadmill walking in community-dwelling healthy seniors. Gait Posture. 2012;36(3):444-8.

101. Monaghan K, Delahunt E, Caulfield B. Increasing the number of gait trial recordings maximises intra-rater reliability of the CODA motion analysis system. Gait Posture. 2007;25(2):303-15.

102. Maynard V, Bakheit A, Oldham J, Freeman J. Intra-rater and inter-rater reliability of gait measurements with CODA mpx30 motion analysis system. Gait Posture. 2003;17(1):59-67.

103. Diss CE. The reliability of kinetic and kinematic variables used to analyse normal running gait. Gait Posture. 2001;14(2):98-103.

104. Kadaba M, Ramakrishnan H, Wootten M, Gainey J, Gorton G, Cochran G. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. J Orthop Res. 1989;7(6):849-60.

105. Steinwender G, Saraph V, Scheiber S, Zwick EB, Uitz C, Hackl K. Intrasubject repeatability of gait analysis data in normal and spastic children. Clin Biomech. 2000;15(2):134-9.

106. Mackey AH, Walt SE, Lobb GA, Stott NS. Reliability of upper and lower limb three-dimensional kinematics in children with hemiplegia. Gait Posture. 2005;22(1):1-9.

107. Yavuzer G, Öken Ö, Elhan A, Stam HJ. Repeatability of lower limb three-dimensional kinematics in patients with stroke. Gait Posture. 2008;27(1):31-5.

108. Caty GD, Detrembleur C, Bleyenheuft C, Lejeune TM. Reliability of lower limb kinematics, mechanics and energetics during gait in patients after stroke. J Rehabil Med. 2009;41(7):588-90.

109. Robbins SM, Wilson JLA, Rutherford DJ. Reliability of principal components and discrete parameters of knee angle and moment gait waveforms in individuals with moderate knee osteoarthritis. Gait Posture. 2013;38(3):421-7.

110. Laroche D, Duval A, Morisset C, Athis P, Ornetti P. Test–retest reliability of 3D kinematic gait variables in hip osteoarthritis patients. Osteoarthritis Cartilage. 2011;19(2):194-9.

111. Angel A, Soraya N, Enrique R. Gait kinematic analysis in patients with a mild form of central cord syndrome. J Neuroeng Rehabil. 2011;8(7).

112. Gorton GE, Hebert DA, Gannotti ME. Assessment of the kinematic variability among 12 motion analysis laboratories. Gait Posture. 2009;29(3):398-402.

113. Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. Aust J Physiother. 2009;55(3):153-69.

114. Schwartz MH, Trost JP, Wervey RA. Measurement and management of errors in quantitative gait data. Gait Posture. 2004;20(2):196-203.

115. Baker R, Mcginley JL, Schwartz MH, Beynon S, Rozumalski A, Graham HK, et al. The gait profile score and movement analysis profile. Gait Posture. 2009;30(3):265-9.

116. Klejman S, Andrysek J, Dupuis A, Wright V. Test-retest reliability of discrete gait parameters in children with cerebral palsy. Arch Phys Med Rehabil. 2010;91(5):781-7.

117. Mcdermott A, Bolger C, Keating L, Mcevoy L, Meldrum D. Reliability of three-dimensional gait analysis in cervical spondylotic myelopathy. Gait Posture. 2010;32(4):552-8.

118. Fitzpatrick R, Mccloskey D. Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. J Physiol. 1994;478(Pt 1):173.

119. Lloyd DG, Li SK. Sensori-motor function, gait patterns and falls in community-dwelling women. Age Ageing. 1996;25(4):292-9.

120. Zeni JA, Higginson JS. Dynamic knee joint stiffness in subjects with a progressive increase in severity of knee osteoarthritis. Clin Biomech. 2009;24(4):366-71.

121. Astephen JL, Deluzio KJ, Caldwell GE, Dunbar MJ. Biomechanical changes at the hip, knee, and ankle joints during gait are associated with knee osteoarthritis severity. J Orthop Res. 2008;26(3):332-41.

122. Chen CP, Chen MJ, Pei Y-C, Lew HL, Wong P-Y, Tang SF. Sagittal plane loading response during gait in different age groups and in people with knee osteoarthritis. Am J Phys Med Rehabil. 2003;82(4):307-12.

123. Huang SC, Wei IP, Chien HL, Wang TM. Effects of severity of degeneration on gait patterns in patients with medial knee osteoarthritis. Med Eng Phys. 2008;30(8):997-1003.

124. Hubley CL, Hill NA, Rutherford DJ, Dunbar MJ, Stanish WD. Co-activation differences in lower limb muscles between asymptomatic controls and those with

varying degrees of knee osteoarthritis during walking. Clin Biomech. 2009;24(5):407-14.

125. Zeni JA, Rudolph K, Higginson JS. Alterations in quadriceps and hamstrings coordination in persons with medial compartment knee osteoarthritis. J Electromyogr Kinesiol. 2010;20(1):148-54.

126. Rudolph KS, Schmitt LC, Lewek MD. Age-related changes in strength, joint laxity, and walking patterns: are they related to knee osteoarthritis? Phys Ther. 2007;87(11):1422-32.

127. Lewek MD, Rudolph KS, Snyder L. Control of frontal plane knee laxity during gait in patients with medial compartment knee osteoarthritis. Osteoarthritis Cartilage. 2004;12(9):745-51.

128. Lewek MD, Scholz J, Rudolph KS, Snyder L. Stride-to-stride variability of knee motion in patients with knee osteoarthritis. Gait Posture. 2006;23(4):505-11.

129. Hunt MA, Wrigley TV, Hinman RS, Bennell KL. Individuals with severe knee osteoarthritis (OA) exhibit altered proximal walking mechanics compared with individuals with less severe OA and those without knee pain. Arthritis Rheum. 2010;62(10):1426-32.

130. Bejek Z, Paróczai R, Illyés Á, Kiss RM. The influence of walking speed on gait parameters in healthy people and in patients with osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2006;14(7):612-22.

131. Landry SC, Mckean KA, Stanish WD, Deluzio KJ. Knee biomechanics of moderate OA patients measured during gait at a self-selected and fast walking speed. J Biomech. 2007;40(8):1754-61.

132. Linley HS, Sled EA, Culham EG, Deluzio KJ. A biomechanical analysis of trunk and pelvis motion during gait in subjects with knee osteoarthritis compared to control subjects. Clin Biomech. 2010;25(10):1003-10.

133. Mündermann A, Dyrby CO, Andriacchi TP. Secondary gait changes in patients with medial compartment knee osteoarthritis: increased load at the ankle, knee, and hip during walking. Arthritis Rheum. 2005;52(9):2835-44.

134. Dieppe PA. Relationship between symptoms and structural change in osteoarthritis. what are the important targets for osteoarthritis therapy? J Rheumatol. 2004:50-3.

135. Andriacchi TP, Mündermann A. The role of ambulatory mechanics in the initiation and progression of knee osteoarthritis. Curr Opin Rheumatol. 2006;18(5):514-8.
136. Hunt MA, Bennell KL. Predicting dynamic knee joint load with clinical measures in people with medial knee osteoarthritis. Knee. 2011;18(4):231-4.
137. Baert I, Jonkers I, Staes F, Luyten F, Truijen S, Verweijen S, et al. Changes in gait kinematics and kinetics associated with structural joint degeneration in knee osteoarthritis. Gait Posture. 2012;36:S89-S90.
138. Kaufman KR, Hughes C, Morrey BF, Morrey M, An KN. Gait characteristics of patients with knee osteoarthritis. J Biomech. 2001;34(7):907-15.
139. Briem K, Axe MJ, Snyder L. Medial knee joint loading increases in those who respond to hyaluronan injection for medial knee osteoarthritis. J Orthop Res. 2009;27(11):1420-5.
140. Mundermann A, Dyrby CO, Andriacchi TP. Secondary gait changes in patients with medial compartment knee osteoarthritis: increased load at the ankle, knee, and hip during walking. Arthritis Rheum. 2005;52(9):2835-44.
141. Nagano Y, Naito K, Saho Y, Torii S, Ogata T, Nakazawa K, et al. Association between in vivo knee kinematics during gait and the severity of knee osteoarthritis. Knee. 2012;19(5):628-32.
142. Heiden TL, Lloyd DG, Ackland TR. Knee joint kinematics, kinetics and muscle co-contraction in knee osteoarthritis patient gait. Clin Biomech. 2009;24(10):833-41.
143. Childs JD, Sparto PJ, Fitzgerald GK, Bizzini M, Irrgang JJ. Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis. Clin Biomech. 2004;19(1):44-9.
144. Briem K, Ramsey DK. The role of bracing. Sports Med Arthrosc. 2013;21(1):11-7.
145. Wilson JA, Deluzio K, Dunbar M, Caldwell G, Hubley C. The association between knee joint biomechanics and neuromuscular control and moderate knee osteoarthritis radiographic and pain severity. Osteoarthritis Cartilage. 2011;19(2):186-93.

146. Deluzio KJ, Astephen JL. Biomechanical features of gait waveform data associated with knee osteoarthritis: an application of principal component analysis. Gait Posture. 2007;25(1):86-93.

147. Baert IA, Jonkers I, Staes F, Luyten FP, Truijen S, Verschueren SM. Gait characteristics and lower limb muscle strength in women with early and established knee osteoarthritis. Clin Biomech. 2013;28(1):40-7.

148. Wessel J, Kaup C, Fan J, Ehalt R, Ellsworth J, Speer C, et al. Isometric strength measurements in children with arthritis: reliability and relation to function. Arthritis Rheum. 1999;12(4):238-46.

149. Talbot LA, Musiol RJ, Witham EK, Metter EJ. Falls in young, middle-aged and older community dwelling adults: perceived cause, environmental factors and injury. BMC Public Health. 2005;5(1):1.

150. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol. 1988;15(12):1833-40.

151. Bellamy N, Kirwan J, Boers M, Brooks P, Strand V, Tugwell P, et al. Recommendations for a core set of outcome measures for future phase III clinical trials in knee, hip, and hand osteoarthritis. consensus development at OMERACT III. J Rheumatol. 1997;24(4):799-802.

152. Mcconnell S, Kolopack P, Davis AM. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): a review of its utility and measurement properties. Arthritis Rheum. 2001;45(5):453-61.

153. Tubach F, Ravaud P, Baron G, Falissard B, Logeart I, Bellamy N, et al. Evaluation of clinically relevant changes in patient reported outcomes in knee and hip osteoarthritis: the minimal clinically important improvement. Ann Rheum Dis. 2005;64(1):29-33.

154. Kuptniratsaikul V, Rattanachaiyanont M. Validation of a modified Thai version of the Western Ontario and McMaster (WOMAC) osteoarthritis index for knee osteoarthritis. Clin Rheumatol. 2007;26(10):1641-5.

155. Pai YC, Rymer WZ, Chang RW, Sharma L. Effect of age and osteoarthritis on knee proprioception. Arthritis Rheum. 1997;40(12):2260-5.

156. Sharma L, Pai Y-C. Impaired proprioception and osteoarthritis. Curr Opin Rheumatol. 1997;9(3):253-8.

157. Barrett D, Cobb A, Bentley G. Joint proprioception in normal, osteoarthritic and replaced knees. J Bone Joint Surg Br. 1991;73(1):53-6.

158. Lattanzio PJ, Petrella RJ. Knee proprioception: a review of mechanisms, measurements, and implications of muscular fatigue. Orthopedics. 1998;21(4):463-71.

159. Slemenda C, Brandt KD, Heilman DK, Mazzuca S, Braunstein EM, Katz BP, et al. Quadriceps weakness and osteoarthritis of the knee. Ann Intern Med. 1997;127(2):97-104.

160. Sharma L, Hayes KW, Felson DT, Buchanan TS, Kirwan G, Lou C, et al. Does laxity alter the relationship between strength and physical function in knee osteoarthritis? Arthritis Rheum. 1999;42(1):25-32.

161. Esrafilian A, Karimi MT, Amiri P, Fatoye F. Performance of subjects with knee osteoarthritis during walking: differential parameters. Rheumatol Int. 2013;33(7):1753-61.

162. Schmitt D, Vap A, Queen RM. Effect of end-stage hip, knee, and ankle osteoarthritis on walking mechanics. Gait Posture. 2015;42(3):373-9.

163. Debi R, Mor A, Segal O, Segal G, Debbi E, Agar G, et al. Differences in gait patterns, pain, function and quality of life between males and females with knee osteoarthritis: a clinical trial. BMC Musculoskelet Disord. 2009;10:127.

164. Winter DA. Biomechanics and motor control of human movement. 4th, editor: John Wiley and Sons; 2009.

165. Brinkmann JR, Perry J. Rate and range of knee motion during ambulation in healthy and arthritic subjects. Phys Ther. 1985;65(7):1055-60.

166. Stauffer RN, Chao EY, Gyory AN. Biomechanical gait analysis of the diseased knee joint. Clin Orthop Relat Res. 1977;126:246-55.

167. Zahrani K, Bakheit A. A study of the gait characteristics of patients with chronic osteoarthritis of the knee. Disabil Rehabil. 2002;24(5):275-80.

168. Gök H, Ergin S, Yavuzer G. Kinetic and kinematic characteristics of gait in patients with medial knee arthrosis. Acta Orthop Scand. 2002;73(6):647-52.

169. Zeni JA, Higginson JS. Differences in gait parameters between healthy subjects and persons with moderate and severe knee osteoarthritis: a result of altered walking speed? Clin Biomech. 2009;24(4):372-8.

170. Briem K, Snyder L. Proximal gait adaptations in medial knee OA. J Orthop Res. 2009;27(1):78-83.

171. Saari T, Carlsson L, Karlsson J, Kärrholm J. Knee kinematics in medial arthrosis dynamic radiostereometry during active extension and weight-bearing. J Biomech. 2005;38(2):285-92.

172. Chang AH, Chmiel JS, Moisio KC, Almagor O, Zhang Y, Cahue S, et al. Varus thrust and knee frontal plane dynamic motion in persons with knee osteoarthritis. Osteoarthritis Cartilage. 2013;21(11):1668-73.

173. Fukaya T, Mutsuzaki H, Wadano Y. Kinematic analysis of knee varus and rotation movements at the initial stance phase with severe osteoarthritis of the knee. Knee. 2015;22(3):213-6.

174. Gore DR, Sepic SB, Mollinger LA. Antalgic maneuvers during walking in men with unilateral knee disability. Clin Orthop Relat Res. 1985;199:192-200.

175. Robon MJ, Perell KL, Fang M, Guererro E. The relationship between ankle plantar flexor muscle moments and knee compressive forces in subjects with and without pain. Clin Biomech. 2000;15(7):522-7.

176. Fisher NM, White SC, Yack HJ, Smolinski RJ, Pendergast DR. Muscle function and gait in patients with knee osteoarthritis before and after muscle rehabilitation. Disabil Rehabil. 1997;19(2):47-55.

APPENDICES

APPENDIX A
THE ETHICAL COMMITEE ON RESEARCH INVOLVING HUMAN SUBJECT

AF 01_12

คณะอนุกรรมการจริยธรรมการวิจัยในคน มหาวิทยาลัยธรรมศาสตร์ ชุดที่ 3 สาขาวิทยาศาสตร์
อาคารราชสุดา ชั้น 1 ภายในศูนย์วิจัยฯ คณะพยาบาลศาสตร์ ต.คลองหนึ่ง อ.คลองหลวง จ.ปทุมธานี 12121
โทรศัพท์: 0-2986-9213 ต่อ 7373 โทรสาร: 0-2516-5381 E-mail: ecsctu3@nurse.tu.ac.th

COA No. 056/2559

ใบรับรองโครงการวิจัย

โครงการวิจัยที่ : 085/2558

ชื่อโครงการวิจัย : การเปลี่ยนแปลงรูปแบบการเดิน การทรงตัวในผู้สูงอายุและผู้สูงอายุที่มีปัญหาข้อขาเสื่อมและความสัมพันธ์กับอัตราการเกิดการล้มและปัจจัยเสี่ยงการล้ม

: CHANGES IN GAIT AND BALANCE IN OLDER PEOPLE AND OLDER PEOPLE WITH LOWER EXTREMITY OSTEOARTHRITIS AND THEIR RELATIONSHIP TO RATE AND RISK OF FALLING IN THE POPULATIONS.

ผู้วิจัยหลัก : ผู้ช่วยศาสตราจารย์ ดร.ไพลวรรณ สัทธานนท์

หน่วยงาน : คณะสหเวชศาสตร์ มหาวิทยาลัยธรรมศาสตร์

คณะอนุกรรมการพิจารณาจริยธรรมการวิจัยในคน มหาวิทยาลัยธรรมศาสตร์ ชุดที่ 3 ได้พิจารณาโดยใช้หลัก ของ The International Conference on Harmonization – Good Clinical Practice (ICH-GCP) อนุมัติให้ดำเนินการศึกษาวิจัยเรื่องดังกล่าวได้

ลงนาม.. (ศาสตราจารย์ ดร.ประนอม โอทกานนท์) ประธานคณะอนุกรรมการ

ลงนาม.. (อาจารย์ ดร.สารรัตน์ วุฒิอาภา) อนุกรรมการและเลขานุการ

วันที่รับรอง : 13 มกราคม 2559

วันหมดอายุ : 13 มกราคม 2560

กำหนดส่งรายงานความก้าวหน้า: ครั้งที่ 1: 13 กรกฎาคม 2559

เอกสารที่คณะอนุกรรมการรับรอง

1) โครงการวิจัย
2) ข้อมูลสำหรับประชากร/กลุ่มตัวอย่างหรือผู้มีส่วนร่วมในการวิจัยและใบยินยอมของประชากร/กลุ่มตัวอย่างหรือผู้มีส่วนร่วมในการวิจัย
3) ผู้วิจัย
4) เอกสารเครื่องมือต่างๆ ที่ใช้ในการวิจัย เป็นต้นว่า แบบสอบถาม
5) เอกสารอื่นๆ ที่เกี่ยวข้อง เช่น เอกสารประชาสัมพันธ์ เป็นต้น

APPENDIX B
DATA COLLECTION FORM

ผู้สูงอายุ: ชื่อ / สกุล ________________________________ **อายุ** _____ ปี **วันที่** ___________

เพศ ☐ ชาย ☐ หญิง **สถานภาพ** ☐ โสด ☐ คู่ ☐ หย่า ☐ หม้าย

ระดับการศึกษา ☐ ไม่ได้ศึกษา ☐ ประถมต้น ☐ ประถมปลาย ☐ มัธยมปลาย

☐ ปริญญาตรี ☐ สูงกว่าปริญญาตรี

อาชีพปัจจุบัน ☐ ทำงาน (ระบุ ____________________)

☐ ไม่ได้ทำงาน (หน้าที่รับผิดชอบปัจจุบัน ___________ อาชีพก่อนเกษียณ ________)

ที่อยู่ ________บ้านเลขที่ ___________หมู่บ้าน _________ตำบล ___________อำเภอ ____________

จังหวัด ______________โทรศัพท์ ______________สถานพยาบาลที่ใกล้ที่สุด__________________________

ข้อมูลสุขภาพพื้นฐาน:

1. โรคประจำตัว:

- ____
- ____
- ____
- ____
- ____

2. ยาที่รับประทาน

- จำนวนยาที่ต้องรับประทานประจำ __________ชนิด
- รายการยาที่รับประทานเป็นประจำ

- ____________________	- ____________________
- ____________________	- ____________________
- ____________________	- ____________________
- ____________________	- ____________________
- ____________________	- ____________________

3. ความสามารถในการเดินด้วยตนเอง

1. สามารถเดินได้ด้วยตนเองโดยไม่ใช้เครื่องช่วยเดินเป็นระยะทาง______________เมตร

2. ใช้เครื่องช่วยเดินหรือไม่

☐ ใช้ ☐ ไม่ใช้

3. สามารถเดินภายนอกบ้านได้เป็นระยะทางอย่างน้อย 10 เมตร ใช่หรือไม่

☐ ใช่ ☐ ไม่ใช่

ถ้าใช่ ต้องใช้เครื่องช่วยเดินหรือไม่

☐ ใช้ โดยเครื่องช่วยเดินนั้นคือ___________________

☐ ไม่ใช้

4. ประวัติการดำเนินโรค

1. วันที่ได้รับการวินิจฉัยว่าเป็นโรคข้อเข่าเสื่อม

☐ Lt. Knee_______________________ ☐ Rt. Knee_________________________

2. อาการแสดงที่สำคัญ

☐ อาการปวด

☐ ขาอ่อนแรง

☐ จำกัดการเคลื่อนไหว

☐ การทรงตัวบกพร่อง ไม่มั่นคง

3. การรักษาที่ได้รับ

☐ รับประทานยา _____________________________________

☐ ฉีดยา ____

☐ ฉีดน้ำหล่อเลี้ยง ___________________________________

☐ อื่นๆ____

5. การรับรู้ของข้อต่อ **(Proprioceptive sense)**

	Angle	**Ordinal Numbers**	**Left**	**Right**
Knee joint	30	1		
		2		
		3		
	80	1		
		2		
		3		

6. ความแข็งแรงของกล้ามเนื้อ **(Muscle strength)**

Muscle	**Ordinal Numbers**	**Left**	**Right**
Quadriceps muscle	1		
	2		
	3		

APPENDIX C
HISTORY OF SELF-REPORTED FALLING

1. คุณเคยล้มหรือไม่?

- ถ้าเคยล้ม ในช่วงหนึ่งเดือนที่ผ่านมา คุณล้มกี่ครั้ง ________
- ในช่วง 6 เดือนที่ผ่านมา คุณล้มกี่ครั้ง ________
- ในช่วง 1 ปีที่ผ่านมา คุณล้มกี่ครั้ง ________

2. คุณบอกได้ไหมว่าอะไรเป็นสาเหตุให้คุณล้ม

2.1 การล้มครั้งล่าสุด

☐ เข่าทรุดไม่มีแรง ☐ สะดุดสิ่งกีดขวาง ☐ วิงเวียนหรือวูบ

☐ ก้าวพลาด ตกบันได ตกหลุม ☐ สัตว์เลี้ยง ☐ อื่นๆ

2.2 การล้มครั้งที่รุนแรงที่สุด

☐ เข่าทรุดไม่มีแรง ☐ สะดุดสิ่งกีดขวาง ☐ วิงเวียนหรือวูบ

☐ ก้าวพลาด ตกบันได ตกหลุม ☐ สัตว์เลี้ยง ☐ อื่นๆ

3. เหตุการณ์หรือกิจกรรมที่กาลังทาอยู่ขณะล้ม

3.1 การล้มครั้งล่าสุด____

3.2 การล้มครั้งที่รุนแรงที่สุด____

4. คุณจาได้ไหมว่าคุณล้มไปทางไหน

4.1 การล้มครั้งล่าสุด ☐ ด้านซ้าย ☐ ด้านขวา ☐ ด้านหน้า ☐ ด้านหลัง

4.2 การล้มครั้งที่รุนแรงที่สุด ☐ ด้านซ้าย ☐ ด้านขวา ☐ ด้านหน้า ☐ ด้านหลัง

5. เวลาที่ล้ม

5.1 การล้มครั้งล่าสุด ☐ เช้า ☐ กลางวัน บ่าย ☐ เย็น ค่ำ ☐ กลางคืน

5.2 การล้มครั้งที่รุนแรงที่สุด ☐ เช้า ☐ กลางวัน บ่าย ☐ เย็น ค่ำ ☐ กลางคืน

6. สถานที่ล้ม

6.1 การล้มครั้งล่าสุด

☐ ห้องนอน ☐ ห้องน้ำ ☐ ห้องครัว ☐ ทางเดินภายในบ้าน ☐ ทางเดินภายนอกบ้าน

☐ บันได ☐ สวน ☐ บริเวณหน้าบ้าน ☐ บริเวณหลังบ้าน ☐ ชุมชน (ระบุ________)

6.2 การล้มครั้งที่รุนแรงที่สุด

☐ ห้องนอน ☐ ห้องน้ำ ☐ ห้องครัว ☐ ทางเดินภายในบ้าน ☐ ทางเดินภายนอกบ้าน

☐ บันได ☐ สวน ☐ บริเวณหน้าบ้าน ☐ บริเวณหลังบ้าน ☐ ชุมชน (ระบุ _______)

7. มีใครเห็นว่าคุณล้มหรือไม่

7.1 การล้มครั้งล่าสุด ☐ มีคนเห็น ☐ ไม่มีคนเห็น

7.2 การล้มครั้งที่รุนแรงที่สุด ☐ มีคนเห็น ☐ ไม่มีคนเห็น

9. คุณมีอาการหมดสติหรือไม่

9.1 การล้มครั้งล่าสุด ☐ หมดสติ ☐ ไม่หมดสติ

9.2 การล้มครั้งที่รุนแรงที่สุด ☐ หมดสติ ☐ ไม่หมดสติ

10. คุณมีอาการบาดเจ็บจากการล้มครั้งดังกล่าวหรือไม่

10.1 การล้มครั้งล่าสุด

☐ ไม่มีการบาดเจ็บ

☐ มีรอยฟกช้ำ ถลอก (บริเวณ____________________________)

☐ มีแผลฉีกขาด และต้องการการเย็บ (บริเวณ_____________________________)

☐ มีกระดูกหัก (บริเวณ________________________________)

☐ มีการบาดเจ็บที่ศีรษะ

10.2 การล้มครั้งที่รุนแรงที่สุด

☐ ไม่มีการบาดเจ็บ

☐ มีรอยฟกช้ำ ถลอก (บริเวณ__________________________)

☐ มีแผลฉีกขาด และต้องการการเย็บ (บริเวณ_______________________________)

☐ มีกระดูกหัก (บริเวณ_______________________________)

☐ มีการบาดเจ็บที่ศีรษะ

11. การรักษาหลังการล้ม

11.1 การล้มครั้งล่าสุด

☐ พบแพทย์ / เข้ารักษาทางโรงพยาบาล

☐ ไม่พบแพทย์ / ไม่เข้ารักษาทางโรงพยาบาล

11.2 การล้มครั้งล่าสุด

☐ พบแพทย์ / เข้ารักษาทางโรงพยาบา

☐ ไม่พบแพทย์ / ไม่เข้ารักษาทางโรงพยาบาล

APPENDIX D
THE WESTERN ONTARIO MCMASTER UNIVERSITIES OSTEOARTHRITIS INDEX (WOMAC)

แบบสอบถาม WOMAC ฉบับภาษาไทย เป็นการประเมินอาการของผู้ป่วยโรคข้อเสื่อม ประกอบด้วยคำถาม 3 ส่วน คือ คำถามระดับความปวด ระดับอาการข้อฝืด และระดับความสามารถในการใช้งานข้อ กรุณากาเครื่องหมาย หรือวงกลมล้อมรอบตัวเลขให้ตรงกับอาการของท่านมากที่สุด

1. ระดับความปวด (0 – 10)

โดย 0 หมายถึงไม่ปวดเลย และ 10 หมายถึงปวดมากจนทนไม่ได้

1.1 ปวดขณะเดิน

0 1 2 3 4 5 6 7 8 9 10

ไม่ปวดเลย ปวดมากจนทนไม่ได้

1.2 ปวดขณะขึ้นลงบันได

0 1 2 3 4 5 6 7 8 9 10

ไม่ปวดเลย ปวดมากจนทนไม่ได้

1.3 ปวดข้อตอนกลางคืน

0 1 2 3 4 5 6 7 8 9 10

ไม่ปวดเลย ปวดมากจนทนไม่ได้

1.4 ปวดข้อขณะอยู่เฉยๆ

0 1 2 3 4 5 6 7 8 9 10

ไม่ปวดเลย ปวดมากจนทนไม่ได้

1.5 ปวดข้อขณะยืนลงน้ำหนัก (ขาข้างนั้นรับน้ำหนักตัว)

0 1 2 3 4 5 6 7 8 9 10

ไม่ปวดเลย ปวดมากจนทนไม่ได้

2. ระดับอาการข้อฝืด, ข้อยึด (0–10)

โดย 0 หมายถึงไม่มีอาการฝืดเลย และ 10 หมายถึง มีอาการฝืดมากที่สุด

2.1 ข้อฝืดช่วงเช้า (ขณะตื่นนอน)

0 1 2 3 4 5 6 7 8 9 10

ไม่ฝืดเลย ฝืดมากที่สุด

2.2 ข้อฝืดในช่วงระหว่างวัน

0 1 2 3 4 5 6 7 8 9 10

ไม่ฝืดเลย ฝืดมากที่สุด

3. ระดับความสามารถในการใช้งานข้อ (0 – 10)

โดย 0 หมายถึงไม่มีอาการฝืดเลย และ 10 หมายถึง ไม่สามารถทำกิจกรรมนั้น ๆ ได้

3.1 การลงบันได

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.2 การขึ้นบันได

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.3 **การลุกยืนจากท่านั่ง**

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.4 **การยืน**

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.5 **การเดินบนพื้นราบ**

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.6 **การขึ้นลงรถยนต์**

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.7 **การไปซื้อ ของนอกบ้าน หรือการไปจ่ายตลาด**

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.8 การใส่กางเกง

0	1	2	3	4	5	6	7	8	9	10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.9 การลุกจากเตียง

0	1	2	3	4	5	6	7	8	9	10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.10 การถอดกางเกง

0	1	2	3	4	5	6	7	8	9	10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.11 การเข้าออกจากห้องอาบน้ำ

0	1	2	3	4	5	6	7	8	9	10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.12 การนั่ง

0	1	2	3	4	5	6	7	8	9	10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.13 การเข้า-ออกจากส้วม

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.14 การทำงานบ้านหนักๆ

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

3.15 การทำงานบ้านเบาๆ

0 1 2 3 4 5 6 7 8 9 10

ทำได้ดีมาก เป็นปัญหามากที่สุด

(ไม่สามารถทำได้)

APPENDIX E
SUBJECT MEASUREMENTS

Mass: ________ kg   Height: ________ mm

<u>Anthropometric data</u>

Anthropometric	Left (mm)	Right (mm)
Inter-ASIS distance (mm)		
Leg length (mm)		
Knee width (mm)		
Ankle width (mm)		
Shoulder offset (mm)		
Elbow width (mm)		
Wrist width (mm)		
Hand thickness (mm)		

Note:

____

____

____

APPENDIX F

RAW DATA OF THE STUDY

Table E1. Descriptive data of participants with knee osteoarthritis

Subject No.	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Knee joint position sense (°)	Knee extension force (n)	Modified WOMAC score			
							Pain	Stiffness	Function	Total scores
1	81	56	158	22.4	16.17	237.05	27	11	92	130
2	64	67	141	33.7	10.50	286.85	15	0	44	59
3	67	81	152	35.1	6.88	209.33	18	9	38	65
4	60	69	149	31.1	7.67	259.38	16	9	57	82
5	69	46	153	19.7	5.92	333.00	9	2	17	28
6	67	63	146	29.6	6.33	250.23	17	8	33	58
7	84	50	164	18.6	7.24	371.65	10	9	41	60
8	60	73	150	32.4	5.03	269.70	10	0	55	65
9	66	55	148	25.1	7.50	308.65	13	6	22	41
10	73	65	160	25.4	11.50	107.87	27	11	92	130
11	60	65	153	27.8	5.10	258.33	26	8	40	74
12	70	62	144	29.9	5.33	377.77	8	4	26	38
13	63	72	166	26.1	8.24	190.43	26	8	33	67
14	64	56	150	24.9	7.67	183.53	21	9	35	65
15	69	49	159	19.4	11.67	209.13	28	8	52	88
16	61	57	149	25.7	16.45	281.78	13	7	19	39
17	69	45	146	21.1	8.33	237.05	18	10	45	73
18	60	67	148	30.6	6.67	269.83	14	0	40	54
19	60	61	154	25.7	5.36	114.15	16	10	41	67
20	60	85	154	35.8	10.54	321.76	33	10	57	100
21	72	89	164	33.1	7.31	281.33	18	8	41	67
22	63	55	144	26.5	10.59	237.05	26	0	61	87
23	67	55	150	24.4	12.17	274.98	27	0	51	78
24	60	61	157	24.7	6.31	374.12	10	0	33	43

Table E2. Descriptive data of participants without knee osteoarthritis

Subject No.	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Knee joint position sense (°)	Knee extension force (n)	Modified WOMAC score			
							Pain	Stiffness	Function	Total scores
1	65	65	162	24.8	1.98	252.22	0	0	0	0
2	61	62	156	25.5	1.84	280.42	0	0	0	0
3	60	66	152	28.6	2.03	232.97	0	0	0	0
4	60	64	145	30.4	2.08	363.64	2	2	9	13
5	70	91	159	36	2.25	258.58	2	0	0	2
6	70	56	156	23	4.25	161.30	0	0	0	0
7	80	65	160	25.4	2.48	229.80	0	0	0	0
8	66	60	154	25.3	1.60	296.91	4	5	12	21
9	63	70	162	26.7	4.50	322.51	0	0	0	0
10	65	51	141	25.7	4.31	264.61	0	0	0	0
11	65	56	148	25.6	1.58	270.11	5	2	6	13
12	60	51	142	25.3	1.84	268.52	0	0	0	0
13	64	61	150	27.1	2.00	240.12	0	0	0	0
14	66	64	153	27.3	2.08	333.18	0	0	0	0
15	66	60	158	24	2.25	235.04	3	0	0	3
16	66	65	164	24.2	4.25	258.28	0	0	0	0
17	62	64	152	27.7	2.00	239.97	0	0	0	0
18	64	73	162	27.8	2.08	285.72	0	0	0	0
19	66	51	155	21.2	2.25	240.67	0	0	0	0
20	73	75	170	26	4.25	262.60	0	0	0	0
21	71	52	153	22.2	1.50	174.34	0	0	0	0
22	60	58	166	21	1.84	307.17	0	0	0	0
23	66	48	140	24.5	2.00	352.74	0	0	0	0
24	67	72	152	31.2	2.08	256.70	0	0	0	0

Table E3. Spatiotemporal data of participants with knee osteoarthritis

Subject No.	Velocity (m/sec)	Cadence (step/min)	Step time (sec)	Step length (m)	Stride time (sec)	Stride length (m)	Single support time (% cycle)	Double support time (% cycle)
1	1.01	111.11	0.56	0.38	1.08	1.09	32.25	36.99
2	0.88	115.44	0.51	0.46	1.04	0.91	32.03	36.55
3	0.71	86.42	0.72	0.54	1.43	1.01	32.53	34.50
4	0.53	88.62	0.72	0.32	1.36	0.74	25.51	50.28
5	0.62	87.52	0.72	0.43	1.40	0.88	29.02	42.39
6	1.00	110.48	0.56	0.54	1.09	1.08	32.20	33.44
7	0.93	96.26	0.66	0.62	1.25	1.16	34.49	29.14
8	0.51	79.65	0.70	0.41	1.51	0.79	24.33	50.01
9	0.94	112.23	0.53	0.53	1.07	1.04	33.97	34.23
10	0.73	95.94	0.62	0.47	1.29	0.91	29.15	42.12
11	0.93	102.88	0.61	0.56	1.17	1.07	30.86	37.70
12	0.98	110.15	0.53	0.52	1.09	1.07	33.35	34.92
13	0.71	84.19	0.72	0.54	1.43	1.01	32.53	34.50
14	0.80	93.27	0.65	0.50	1.29	1.03	32.91	33.41
15	0.73	88.79	0.68	0.49	1.35	0.98	34.28	32.42
16	1.00	110.80	0.54	0.55	1.08	1.08	35.69	29.53
17	0.90	112.15	0.53	0.48	1.07	0.96	33.64	32.71
18	1.15	122.87	0.48	0.50	0.98	1.12	33.87	30.29
19	1.07	113.71	0.54	0.57	1.06	1.13	32.19	33.69
20	0.97	106.52	0.57	0.53	1.13	1.10	31.07	35.79
21	0.85	99.17	0.58	0.53	1.21	1.03	31.40	39.67
22	0.91	102.85	0.58	0.53	1.17	1.06	31.24	37.73
23	0.99	107.14	0.56	0.58	1.12	1.10	34.82	30.36
24	0.74	82.19	0.73	0.55	1.46	1.09	32.88	32.19

Table E4. Spatiotemporal data of participants without knee osteoarthritis

Subject No.	Velocity (m/sec)	Cadence (step/min)	Step time (sec)	Step length (m)	Stride time (sec)	Stride length (m)	Single support time (% cycle)	Double support time (% cycle)
1	1.11	107.14	0.54	0.82	1.12	1.29	34.82	30.36
2	0.95	101.69	0.57	0.58	1.18	1.13	35.59	31.36
3	0.96	118.81	0.51	0.50	1.01	0.97	32.67	34.65
4	0.87	96.77	0.60	0.54	1.24	1.07	29.03	42.74
5	1.03	109.09	0.54	0.55	1.10	1.14	32.73	32.73
6	1.05	110.09	0.56	0.60	1.09	1.14	34.86	30.28
7	0.61	77.92	0.72	0.44	1.54	0.95	29.87	41.56
8	1.11	107.14	0.54	0.82	1.12	1.29	34.82	30.36
9	0.95	101.69	0.57	0.58	1.18	1.13	35.59	31.36
10	0.96	118.81	0.51	0.50	1.01	0.97	32.67	34.65
11	0.87	96.77	0.60	0.54	1.24	1.07	29.03	42.74
12	1.03	109.09	0.54	0.55	1.10	1.14	32.73	32.73
13	0.88	108.11	0.56	0.50	1.11	0.97	32.43	34.23
14	1.06	113.21	0.54	0.55	1.06	1.13	33.02	31.13
15	1.24	116.50	0.50	0.61	1.03	1.27	37.86	26.21
16	1.37	114.29	0.51	0.70	1.05	1.44	38.10	24.76
17	1.20	113.21	0.54	0.63	1.06	1.27	34.91	27.36
18	1.23	111.11	0.54	0.66	1.08	1.33	34.26	30.56
19	1.07	116.51	0.56	0.56	1.03	1.11	31.07	33.98
20	1.15	106.19	0.54	0.61	1.13	1.30	36.28	30.97
21	0.96	118.81	0.51	0.50	1.01	0.97	32.67	34.65
22	1.06	113.21	0.54	0.55	1.06	1.13	33.02	31.13
23	0.77	103.45	0.57	0.44	1.16	0.89	32.76	36.21
24	1.06	113.21	0.54	0.55	1.06	1.13	33.02	31.13

Table E5. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants with knee osteoarthritis: at initial contact

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	37.89	2.34	-16.79	5.10	-2.38	-15.03	7.90	-12.89	4.18
2	37.59	5.59	-20.45	6.40	-7.82	9.09	9.65	-12.10	2.25
3	29.27	-5.26	-12.24	6.01	6.95	-13.04	4.83	-9.54	-5.11
4	31.34	0.89	-19.52	6.30	2.06	-11.28	-1.28	10.22	-9.75
5	41.29	-5.03	2.41	-1.81	7.24	-10.38	5.38	-7.18	2.00
6	7.18	1.71	-14.29	-12.50	3.64	-11.40	-3.40	0.32	0.53
7	21.41	-6.68	-16.78	8.49	8.51	4.68	4.68	0.94	-11.20
8	29.11	-1.58	-8.37	-3.65	-3.52	0.38	0.38	-5.20	0.49
9	11.21	-16.75	-19.23	-6.70	8.41	2.06	2.06	-6.20	2.55
10	31.43	2.05	-4.13	2.11	-2.42	8.45	8.45	-4.90	2.03
11	23.32	0.30	-10.74	7.02	-4.76	-5.40	-5.40	1.35	1.47
12	33.06	-0.88	-13.72	8.29	-1.90	7.27	7.27	-1.88	0.98
13	33.32	-4.15	-22.94	0.37	4.75	-8.77	6.04	-4.21	2.08
14	23.81	4.49	-11.61	6.12	2.85	-13.87	5.65	-1.35	2.06
15	21.13	-2.34	-8.84	-0.69	1.04	3.14	3.14	-2.55	-6.48
16	23.61	-0.01	-13.17	-2.70	-2.51	1.27	1.27	0.32	1.69
17	26.08	0.02	-21.44	4.22	-0.20	-6.73	0.35	-5.10	2.08
18	26.08	0.02	-21.44	4.22	-0.20	-6.73	0.35	-5.10	2.06
19	31.75	-2.49	-10.08	4.56	-2.12	7.58	7.58	-6.37	3.85
20	28.24	-2.47	11.46	3.99	6.68	6.85	6.85	-1.47	2.57
21	28.84	-1.44	-20.24	6.25	6.82	9.19	9.19	-2.42	4.22
22	35.29	-0.28	1.90	8.01	4.90	-13.24	2.22	-5.73	2.80
23	16.20	-4.54	-12.60	3.21	4.90	-0.73	11.54	2.09	-5.22
24	40.93	-3.34	18.38	-8.66	14.02	-23.95	0.18	5.00	-9.76

Table E6. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants without knee osteoarthritis: at initial contact

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	36.29	1.29	-9.16	2.29	-3.78	-5.69	1.37	-7.71	1.17
2	39.89	-0.92	-11.08	8.22	-6.06	-8.43	12.14	-9.88	3.71
3	30.40	2.74	-11.74	7.74	-5.30	-8.38	11.08	-9.13	3.33
4	38.00	-1.49	-4.14	2.39	0.70	-10.16	-8.38	-4.90	-7.57
5	33.92	-2.08	-1.58	3.36	1.01	-6.07	1.89	-3.37	2.64
6	40.37	-0.74	-11.10	-0.81	-1.45	-9.54	7.45	-8.91	2.48
7	33.50	-1.13	12.12	0.98	3.29	-1.29	-13.47	-0.46	-5.74
8	23.26	-1.19	12.30	-0.85	4.57	-13.02	1.74	1.00	1.96
9	26.06	-5.32	-12.53	5.15	4.52	-8.33	-9.24	-4.1	0.81
10	17.60	3.45	-6.98	-4.31	-1.32	-9.59	-0.20	-8.03	0.71
11	24.00	6.50	-5.40	11.49	-9.28	-12.42	1.34	-6.98	1.14
12	35.80	-0.64	-7.56	7.06	-1.76	-12.92	5.85	-3.80	1.66
13	33.74	-1.57	-6.96	7.23	-5.26	-12.79	3.83	-9.87	2.04
14	35.93	5.06	-11.88	0.60	-7.54	-5.21	3.48	-4.25	-4.21
15	25.89	-1.49	-7.68	4.40	0.25	-6.83	8.10	-1.06	-7.06
16	30.44	0.11	2.79	8.27	-3.93	-14.85	4.01	1.07	-6.74
17	26.25	-0.68	-10.72	1.45	2.13	-12.74	4.54	-2.25	3.65
18	35.16	-4.75	-11.48	1.01	3.59	-16.29	5.23	-3.89	0.61
19	23.37	-2.12	-12.04	5.23	3.98	-11.54	8.08	-1.28	1.10
20	29.52	-3.88	-7.97	1.90	-0.30	-10.53	3.61	-4.85	4.93
21	25.94	-6.98	-6.63	1.75	2.75	-13.57	6.13	-4.16	2.69
22	26.05	-3.02	-7.36	7.50	1.00	-9.76	-1.40	-2.44	0.36
23	40.83	-6.10	-5.01	5.18	-1.27	-9.41	5.90	-2.33	-7.51
24	38.28	-0.25	-7.23	4.06	-3.47	-8.87	8.70	-1.85	0.59

Table E7. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants with knee osteoarthritis: at mid stance

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	13.67	4.22	-12.13	2.74	1.16	-10.94	4.18	-13.84	3.93
2	10.19	11.15	-23.40	9.79	-6.84	7.20	17.06	-10.53	-4.00
3	4.42	-1.51	-11.04	10.86	10.00	-3.03	15.48	-8.97	3.00
4	11.56	1.73	-14.95	5.50	4.36	-10.06	14.29	9.46	0.73
5	11.65	1.56	0.99	3.25	9.88	-9.29	6.06	-5.23	1.65
6	11.87	1.43	-14.64	5.28	4.58	-9.06	14.76	9.29	1.73
7	7.36	-1.57	-17.35	2.32	10.11	-5.51	6.55	0.75	-10.06
8	10.66	9.58	-5.47	3.10	-4.36	-11.05	9.45	-4.93	3.16
9	8.65	-11.86	-16.75	-0.97	7.99	-11.13	8.15	-7.9	-5.22
10	7.58	5.56	-15.62	5.84	-3.92	-0.24	13.72	-6.44	3.80
11	3.67	6.00	-18.39	9.73	-5.60	-4.18	5.61	2.13	0.66
12	11.64	7.11	-7.98	13.83	-2.35	-7.71	13.96	-0.42	-1.68
13	8.43	3.72	-20.04	-1.46	7.83	-9.05	7.33	-1.85	0.87
14	5.33	5.44	0.42	6.82	5.82	-12.52	11.46	-0.01	-3.45
15	10.44	2.85	-22.55	12.32	-1.57	-2.96	13.63	0.80	-7.3
16	7.55	3.27	-17.67	0.06	-2.83	11.15	6.10	2.73	-8.18
17	4.80	6.65	-15.24	15.39	-3.30	-4.37	15.00	-3.47	1.24
18	4.67	6.29	-15.36	14.67	-3.11	-3.77	14.56	-5.65	1.11
19	9.81	11.03	-10.50	9.58	-2.41	-10.71	9.62	-2.53	1.97
20	4.69	3.79	12.44	6.71	9.79	-12.50	14.96	0.39	-3.84
21	9.56	1.36	-22.32	8.30	9.11	-6.62	14.63	-1.16	7.82
22	17.46	2.87	2.24	9.29	5.10	-20.09	10.25	-5.81	0.63
23	-2.41	0.75	-16.00	11.08	2.58	2.21	14.93	-2.62	-7.24
24	16.89	-9.30	-1.03	-25.90	16.90	-27.51	6.23	5.91	4.35

Table E8. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants without knee osteoarthritis: at mid stance

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	16.88	7.79	-0.13	14.50	-2.58	-18.22	12.76	-2.56	3.73
2	11.94	8.67	-5.41	10.63	-5.77	-19.39	18.21	-11.52	0.34
3	7.42	6.25	-10.06	7.98	-1.18	-11.99	18.43	-12.35	3.62
4	19.70	4.79	-20.35	6.20	-0.91	-15.30	6.91	-6.71	3.00
5	19.45	7.18	-3.57	9.86	0.83	-17.18	7.46	-2.00	-3.64
6	18.49	5.13	-16.24	6.43	-4.51	-3.56	15.49	-8.89	2.92
7	11.12	4.65	13.47	6.75	5.59	-12.24	5.16	-0.53	-7.08
8	6.50	4.79	7.00	-2.25	1.83	-7.01	6.07	1.36	3.42
9	5.71	1.92	-14.28	9.53	3.63	-0.80	1.53	0.98	2.87
10	0.88	5.59	-9.45	6.32	-2.11	-10.91	16.30	-8.08	4.66
11	5.92	10.30	-9.21	15.83	-7.77	-13.49	13.97	-3.74	-1.90
12	14.29	6.83	-14.59	7.45	-2.73	-5.59	12.42	-4.77	1.42
13	5.95	7.76	-20.46	4.91	-1.86	-11.12	11.20	-7.15	2.85
14	13.91	10.75	-18.26	6.57	-7.88	-14.27	12.53	-4.79	0.54
15	1.49	7.05	-9.00	5.19	0.97	-7.04	11.81	-0.43	-11.49
16	6.94	12.66	4.37	6.06	-3.67	-9.07	8.77	0.88	-6.98
17	5.95	5.24	-14.56	9.55	1.52	-3.30	12.33	-1.94	9.55
18	15.05	3.06	-8.84	12.72	2.47	-8.39	15.34	-0.23	-11.29
19	2.00	6.21	-11.26	10.61	3.00	-3.08	14.45	-0.11	-10.85
20	5.81	6.84	-12.08	6.08	-1.17	-6.64	9.89	-3.18	1.65
21	8.55	-2.66	-13.92	8.39	11.10	-2.88	9.72	-3.22	4.24
22	5.50	2.98	-8.38	10.34	1.39	-11.62	6.54	-2.39	3.87
23	14.47	4.63	3.15	10.48	0.26	-16.76	10.47	-1.71	1.13
24	6.93	6.10	-9.61	7.89	-3.13	-10.25	11.40	-2.84	3.85

Table E9. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants with knee osteoarthritis: at toe off

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	4.54	-5.95	-8.75	27.91	-13.74	-2.53	-13.11	-4.27	1.98
2	3.87	3.42	-14.54	36.37	-12.87	2.24	-8.05	-6.32	0.72
3	-9.17	-10.54	-11.86	34.72	-4.64	-2.11	-16.51	-9.00	1.41
4	4.88	-11.67	-10.56	41.60	3.73	-9.98	-17.39	10.32	10.00
5	5.95	-13.77	2.89	43.44	9.42	-11.96	-9.66	-5.15	6.46
6	-13.82	-1.14	-6.77	24.57	6.41	-8.69	-16.61	1.90	-4.00
7	7.10	-7.03	-8.95	37.64	2.69	7.46	4.36	3.74	-6.87
8	3.60	-6.45	-3.53	40.67	-0.97	-9.58	-16.90	-3.70	2.12
9	-15.93	-13.10	-15.20	30.22	6.54	-11.64	-17.68	-8.11	3.70
10	1.41	-7.39	-9.81	37.37	-5.60	2.38	-14.06	-4.62	4.33
11	-0.69	-4.50	-4.52	41.63	-13.67	-1.58	-15.54	1.26	2.64
12	6.57	-2.59	-2.32	49.46	0.23	-8.11	-2.83	-0.93	1.23
13	1.70	-7.58	-12.47	42.57	0.61	1.04	-7.37	-2.55	1.71
14	-1.79	-5.54	13.65	32.09	12.95	-11.60	0.47	1.84	-12.77
15	6.71	-7.13	-17.06	49.35	-1.24	-2.41	-6.27	0.70	-6.00
16	-4.98	3.58	-10.46	30.40	-6.58	7.34	2.11	6.37	-2.65
17	-6.57	-6.58	-8.56	42.33	-1.42	-3.96	-6.54	-2.68	-6.36
18	-6.33	-6.31	-8.31	41.45	-1.10	-4.87	-8.88	-2.47	-5.87
19	-3.95	-1.13	0.73	39.40	2.91	-10.74	-9.82	-1.40	2.58
20	-7.73	-8.38	14.53	29.26	6.92	-9.61	-8.81	-2.31	5.34
21	-3.20	-5.16	-15.88	37.66	-0.44	-1.83	-5.57	-1.47	1.54
22	12.26	-1.36	-10.70	32.98	13.40	-10.57	2.27	-3.95	0.86
23	-11.30	-9.62	-4.02	43.46	-15.58	5.70	-3.62	-2.73	3.06
24	10.08	-11.00	-8.75	16.19	11.67	-16.81	3.00	3.91	-3.75

Table E10. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants without knee osteoarthritis: at toe off

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	7.44	-2.18	-3.61	46.21	-2.51	-9.34	-20.19	-4.81	-9.56
2	-0.43	-6.20	-20.80	34.78	-11.34	-8.53	-21.34	-11.20	-4.97
3	-1.67	-7.60	-15.50	37.06	-9.20	-10.48	-4.07	-9.96	4.39
4	9.08	-4.93	-11.43	44.45	-1.94	-9.93	-9.57	-2.61	1.89
5	7.11	-3.80	0.17	38.97	2.98	-5.79	-5.32	-0.48	-3.20
6	3.66	-4.57	-18.27	37.48	-11.47	-1.98	-13.58	-5.69	-4.42
7	2.47	-8.35	12.80	38.14	12.28	-7.52	-19.74	0.82	2.76
8	5.50	-5.71	14.74	32.53	8.32	-4.45	-1.70	2.59	0.21
9	-3.62	-9.83	-16.31	37.56	-7.61	5.80	-14.45	0.98	3.49
10	-2.70	-6.28	-23.59	38.43	-14.01	-5.28	-4.08	-7.20	2.96
11	-9.35	2.55	-1.37	35.90	-1.36	-12.54	-6.36	-2.13	-7.66
12	6.13	-9.44	-24.32	41.36	-9.79	-2.20	-9.70	-2.93	2.02
13	-0.27	-10.87	-23.16	40.24	-13.35	-4.43	-24.62	-7.63	1.73
14	1.05	-1.15	-8.43	41.57	-2.20	-10.11	-10.65	-2.45	0.59
15	-9.22	-5.26	5.23	37.20	7.79	-0.13	-11.63	1.87	-9.21
16	-10.64	-4.44	20.57	32.11	11.90	-4.50	-11.80	3.02	-9.28
17	-10.70	-6.38	-25.28	35.56	-1.27	0.12	-7.94	-1.70	1.66
18	0.17	-6.57	-11.74	38.50	-1.14	-0.39	-1.61	-1.58	-10.74
19	-5.72	-8.30	-16.76	42.28	-6.26	2.39	-10.32	-2.47	-3.62
20	-10.71	-7.42	-7.55	30.54	-2.34	-5.59	-14.90	-4.66	-0.28
21	1.33	-10.24	-22.89	40.34	3.90	6.24	-0.55	-1.64	2.38
22	-5.88	-7.71	-6.82	39.95	0.52	-6.89	-16.32	-2.17	4.45
23	-3.30	-3.54	6.54	33.60	7.01	-5.77	-13.11	-0.78	-2.61
24	10.08	-3.72	-12.07	43.35	-6.95	-3.00	-3.84	-1.98	3.09

Table E11. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants with knee osteoarthritis: at mid swing

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	31.44	-3.47	-17.91	55.07	-8.72	-10.63	6.56	-7.88	-4.83
2	31.37	4.97	-4.64	47.28	-10.32	-1.24	-1.41	-3.21	-2.63
3	27.14	-6.85	-18.24	57.77	-9.01	-6.00	5.85	-3.94	-2.05
4	24.97	-5.95	-3.60	59.09	0.02	-0.55	-10.54	3.09	-2.00
5	35.50	-9.19	5.09	48.64	10.72	-6.10	6.75	0.05	0.06
6	13.57	-7.28	1.63	39.72	3.55	-12.02	-10.19	0.98	-14.00
7	20.01	-8.21	-18.15	39.69	4.10	7.19	8.59	4.36	-9.32
8	24.79	-3.86	-1.17	53.14	1.28	-7.47	-0.96	-2.15	-8.12
9	13.29	-8.41	-4.99	49.86	10.27	-9.16	1.65	-5.86	-7.09
10	27.37	-3.10	-21.37	53.68	-1.38	2.46	5.52	-0.93	1.54
11	22.75	-4.70	-4.67	54.29	-12.77	-1.39	-1.24	0.32	-4.67
12	27.53	-2.53	-5.02	51.35	-0.56	-5.12	9.30	2.22	-8.97
13	30.63	-8.12	-11.21	57.54	-5.95	9.86	6.88	1.83	-9.65
14	13.79	-4.14	4.72	44.88	3.29	-6.27	5.69	3.47	-10.56
15	23.58	-7.42	-13.73	51.61	2.89	-2.58	12.11	2.32	-3.00
16	19.96	-0.74	-15.66	51.29	-6.78	5.98	5.89	6.76	-3.45
17	22.57	-4.60	-5.98	53.63	-3.45	0.47	15.46	1.95	-9.87
18	22.14	-4.57	-5.12	53.04	-3.12	0.05	10.15	0.84	-8.15
19	24.16	-1.35	2.18	56.69	8.27	-5.82	3.28	2.63	-6.00
20	24.57	-1.69	21.93	46.63	1.73	-8.68	7.86	0.27	-3.90
21	19.56	-3.40	-17.13	53.37	-2.92	-0.91	6.38	0.50	0.85
22	27.01	-1.31	7.42	42.40	13.44	-20.38	7.26	-2.88	-3.20
23	9.92	-10.27	-32.64	55.07	-17.95	5.14	9.38	-0.25	-2.72
24	29.80	-7.01	9.15	48.38	14.54	3.12	8.30	9.00	-3.40

Table E12. Kinematic data of hip, knee and ankle joints in sagittal, coronal and horizontal planes of participants without knee osteoarthritis: at mid swing

Subject No.	Hip			Knee			Ankle		
	Flexion (+) / Extension (-)	Adduction (+) / Abduction (-)	Internal (+) / External rotation (-)	Flexion (+) / Extension (-)	Varus (+) / Valgus (-)	Internal (+) / External rotation (-)	Dorsiflexion (+) / Plantarflexion (-)	Inversion (+) / Eversion (-)	Internal (+) / External rotation (-)
1	32.41	-0.54	18.87	50.51	6.42	-10.88	2.10	-0.12	-3.01
2	34.00	-1.58	-11.21	52.54	-7.33	-10.52	14.77	-5.34	-2.46
3	23.97	-1.06	-17.78	53.69	-11.55	-4.04	9.41	-2.75	-5.04
4	33.29	-4.20	10.92	51.86	5.12	-10.91	2.44	1.13	-5.25
5	20.12	-4.94	2.49	52.31	5.30	-2.12	-0.41	0.84	-2.86
6	31.37	-3.62	-22.02	53.93	-8.49	-4.09	7.94	-2.24	0.12
7	26.00	-4.57	25.37	50.24	4.23	-8.75	-15.11	-1.37	-10.64
8	19.73	-6.91	19.91	45.02	5.11	-11.06	2.68	4.25	-9.93
9	24.00	-8.69	-26.91	49.72	-11.47	3.61	-4.49	1.64	0.64
10	20.21	-2.27	-22.8	41.29	-9.10	-10.48	8.48	-4.76	-6.42
11	12.47	1.25	10.32	52.70	10.19	-10.78	4.97	2.03	-6.50
12	29.31	-6.15	-14.23	56.93	-5.17	-7.56	4.34	-0.33	-3.07
13	26.82	-4.70	-22.44	59.20	-10.30	-4.65	2.54	-1.36	-3.63
14	27.84	0.38	3.21	57.10	7.29	-8.47	6.42	0.82	-10.51
15	21.80	-2.12	1.29	59.71	1.96	3.65	5.44	3.00	-7.74
16	16.53	-4.58	31.18	53.76	8.81	0.05	-0.39	6.04	-9.47
17	15.86	-7.77	-15.20	57.59	-1.54	3.12	7.32	1.12	-8.20
18	32.11	-6.88	4.65	52.37	10.12	-6.60	10.27	2.65	-4.95
19	20.39	-2.77	-6.05	55.19	-2.18	1.52	9.00	3.30	-10.72
20	22.40	-5.19	-7.03	55.77	-2.97	-1.80	7.14	-0.78	-6.16
21	21.88	-9.46	-9.60	55.91	9.68	6.28	9.07	0.54	-4.35
22	17.60	-7.27	-3.80	58.18	5.49	-7.69	-0.94	-0.19	-1.58
23	30.36	-4.24	6.75	53.00	10.77	-11.89	4.80	-0.28	-5.08
24	32.39	-3.63	-2.24	56.63	-1.16	-12.23	8.99	2.25	-7.24

BIOGRAPHY

Name	Miss Praewpun Saelee
Date of Birth	November12, 1991
Educational Attainment	2015: Bachelor of Science (Physical Therapy), Thammasat University