CORRELATION BETWEEN CLINICAL AND BIOMECHANIC CHARACTERISTICS OF GAIT IN INDIVIDUALS WITH STROKE

SUNEE BOVONSUNTHONCHAI

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Thesis

entitled

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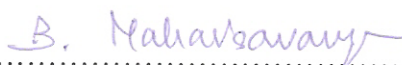

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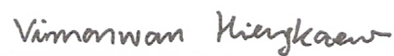

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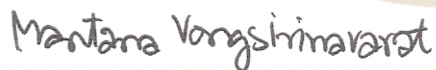

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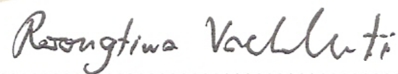

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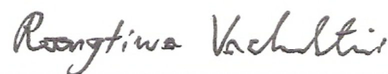

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Sunee Bovonsunthonchai

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CORRELATION BETWEEN CLINICAL AND BIOMECHANIC CHARACTERISTIC OF GAIT IN INDIVIDUALS WITH STROKE

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ABSTRACT

The purpose of the study was to investigate the relationships between clinical measures [muscle tone (hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors), postural balance, and lower extremity motor function] and gait performances [gait speeds (comfortable and fast) and symmetrical gait variables (the first peak vertical and the second peak vertical forces, step, single support, stance, and swing times)] in stroke patients. Additionally, gait biomechanic characteristics at both gait speeds were compared among the control and the un-affected and affected legs of stroke patients. Thirty controls and stroke subjects participated in the study. Vicon^{TM} Motion Analysis System and AMTI force platform were used for analyzing the gait biomechanic characteristics.

The results demonstrated significant ($p<0.05$) negative relationships between lower extremity muscle tones and gait performances, while the postural balance and lower extremity motor function showed significant ($p<0.05$) positive relationships with the gait performances. Therefore, reduction of excessive muscle tone and improvement of postural balance and motor function were necessary for developing gait performances in order to obtain faster gait speed and a more symmetrical pattern.

For the temporo-spatial comparisons, the stroke significantly ($p<0.05$) showed differences in cadence, double support time, step width, stride length and time, and gait speed from the control. Furthermore, the stroke showed significant ($p<0.05$) differences in single support time, step length and time in the un-affected side from the control and the affected side and showed significant ($p<0.05$) differences in the step length and time in the affected side from the control. The difficulty in walking of stroke patients, reduction in cadence, stride length, and gait speed but increase in double support time, step width, and stride time were shown as consequences of the stroke and as compensation for movement. There were significant differences in the hip, knee, and ankle among the control and the un-affected and affected sides for the angular displacements in the sagittal, frontal, and transverse planes at the initial contact, midstance, and toe off, for the angular velocities during the initial and terminal swings, and for the ground reaction forces in the antero-posterior, medio-lateral, and vertical directions. In conclusion, alterations in gait characteristics were observed in both the affected and the un-affected sides. Thus, to remedy the stroke patients, not only the affected side, but also the un-affected side should be of concern.

KEYWORDS: STROKE, GAIT, CORRELATION, BIOMECHANICS, CLINICAL

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ความสัมพันธ์ระหว่างคุณลักษณะทางคลินิกและชีวกลศาสตร์ในการเดินของผู้ป่วยอัมพาตครึ่งซีก
(CORRELATION BETWEEN CLINICAL AND BIOMEHCHANIC CHARACTERISTIC OF GAIT IN INDIVIDUALS WITH STROKE)

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บทคัดย่อ

จุดประสงค์การศึกษานี้เพื่อทำการตรวจสอบความสัมพันธ์ระหว่างตัวแปรทางคลินิก [ความตึงตัวของกล้ามเนื้อหุบตะโพก เหยียดตะโพก เหยียดเข่า กระดกข้อเท้าขึ้น และหมุนข้อเท้าเข้าด้านใน การรักษาสมดุลท่าทาง การควบคุมการทำงานของขา] และความสามารถในการเดิน [ความเร็วในการเดิน (ปกติและเร็ว) และตัวแปรของความสมมาตรในการเดิน (แรงปฏิกิริยาในแนวดิ่งสูงสุดอันแรกและอันที่สอง) ในผู้ป่วยอัมพาตครึ่งซีก นอกจากนี้ ได้ทำการเปรียบเทียบชีวกลศาสตร์การเดินที่ทั้งสองความเร็วระหว่างกลุ่มควบคุม ขาข้างปกติ และอ่อนแรงในผู้ป่วยอัมพาตครึ่งซีก ผู้เข้าร่วมการศึกษานี้ประกอบด้วยกลุ่มควบคุมและกลุ่มผู้ป่วยอัมพาตครึ่งซีกจำนวน 30 คน โดยลักษณะทางชีวกลศาสตร์การเดินทำการวิเคราะห์ด้วยเครื่องวิเคราะห์การเคลื่อนไหวและแผ่นวัดแรงปฏิกิริยา

ผลการศึกษาแสดงถึงความสัมพันธ์เชิงลบอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ระหว่างความตึงตัวของกล้ามเนื้อขาและความสามารถในการเดิน ในขณะที่การรักษาสมดุลท่าทางและการควบคุมการทำงานของขาแสดงถึงความสัมพันธ์เชิงบวกอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) กับความสามารถในการเดิน ดังนั้น การลดความตึงตัวของกล้ามเนื้อที่มากเกินไป และ การพัฒนาการรักษาสมดุลท่าทางและการควบคุมการทำงานของขาจึงมีความจำเป็นต่อการพัฒนาความสามารถในการเดินเพื่อให้ผู้ป่วยสามารถเดินได้ด้วยความเร็วและความสมมาตรที่เพิ่มขึ้น

สำหรับการเปรียบเทียบในตัวแปรเวลาและระยะทาง ผู้ป่วยอัมพาตครึ่งซีกแสดงถึงความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ในจำนวนก้าวต่อนาที เวลาที่เท้าสองข้างสัมผัสพื้น ระยะห่างระหว่างเท้า ระยะทางและเวลาที่ใช้ในหนึ่งวงจรการเดิน และความเร็วการเดินจากกลุ่มควบคุม นอกจากนี้ ผู้ป่วยอัมพาตครึ่งซีกแสดงถึงความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ใน เวลาที่เท้าข้างเดียวสัมผัสพื้น ระยะและเวลาก้าว ของขาข้างปกติจากกลุ่มควบคุมและขาข้างอ่อนแรง และแสดงถึงความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ในระยะและเวลาก้าวของขาข้างอ่อนแรงจากกลุ่มควบคุม จากความยากลำบากในการเดินของผู้ป่วยอัมพาตครึ่งซีก การลดลงของจำนวนก้าวต่อนาที ระยะทางที่เดินได้ในหนึ่งวงจรการเดิน และความเร็วในการเดิน และการเพิ่มขึ้นของเวลาที่เท้าสองข้างสัมผัสพื้น ระยะห่างระหว่างเท้า และเวลาที่ใช้ในหนึ่งวงจรการเดินแสดงถึงผลลัพธ์ที่เกิดขึ้นเมื่อเป็นอัมพาตครึ่งซีกตลอดจนเป็นการเคลื่อนไหวทดแทนที่เกิดขึ้นเมื่อเคลื่อนไหว พบความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ในข้อตะโพก ข้อเข่า และข้อเท้า ระหว่างกลุ่มควบคุม ขาข้างปกติ และขาข้างอ่อนแรง สำหรับการเคลื่อนที่เชิงมุมในระนาบแบ่งซ้าย-ขวา แบ่งหน้า-หลัง และตัดขวาง เมื่อเท้าแตะพื้น ช่วงกลางการเดิน และยกเท้า สำหรับความเร็วเชิงมุมในช่วงต้นและท้ายของการก้าวขา และสำหรับแรงปฏิกิริยาในทิศทาง หน้า-หลัง ใน-นอก และแนวดิ่ง โดยสรุป การเปลี่ยนแปลงด้านชีวกลศาสตร์การเดินสังเกตเห็นได้ทั้งในขาข้างอ่อนแรงและปกติ ดังนั้นในการรักษาผู้ป่วยอัมพาตครึ่งซีก ไม่เพียงแต่การเคลื่อนไหวของด้านอ่อนแรง แต่ด้านปกติก็ควรตระหนักถึงด้วย

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LIST OF ABBREVIATIONS

IC	=	Initial contact
MS	=	Midstance
TO	=	Toe off
DST	=	Double support time
SST	=	Single support time
H	=	Hip velocity during the initial swing
K1	=	Knee velocity during the initial swing
K2	=	Knee velocity during the terminal swing
A1	=	Ankle velocity during the initial swing
A2	=	Ankle velocity during the mid swing
GRFs	=	Ground reaction force (s)
X1	=	First peak lateral force
X2	=	First peak medial force
X3	=	Second peak medial force
Y1	=	Braking peak force
Y2	=	Propulsion peak force
Z1	=	First peak vertical force
Z2	=	Second peak vertical force
TMSE	=	Thai Mental State Examination
BBS	=	Berg Balance Scale
FMA	=	Fugl-Meyer Assessment Scale
MAS	=	Modified Ashworth Scale
COM	=	Center of mass
COG	=	Center of gravity
BOS	=	Base of support
Hz	=	Hertz
PROM	=	Passive range of motion
yr	=	year (s)

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LIST OF ABBREVIATIONS
(Continued)

kg	=	kilogram (s)
cm	=	centimeter (s)
m	=	meter (s)
s	=	second (s)
m/s	=	meter/ second
HA	=	Hip adductors
HE	=	Hip extensors
KE	=	Knee extensors
AP	=	Ankle plantarflexors
AI	=	Ankle invertors
A	=	Affected side
U	=	Un-affected side
SI	=	Symmetry Index
%	=	percent
%GC	=	percentage of gait cycle
%BW	=	percentage of body weight

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CHAPTER I
INTRODUCTION

Stroke, defined by WHO (World Health Organization), is an acute neurological dysfunction of vascular origin with sudden occurrence of symptoms and signs corresponding to the involvement of focal areas in the brain and having the symptoms more than 24 hours (1-3). A great number of the incidence and mortality from cardiovascular disease in Thai populations was reported by Ministry of Public Health in 2002. At present, it was found that the cardiovascular disease is the major disease leading to disability and handicap in Thailand (4). Stroke is a common disease with high mortality and incidence of disability and handicap among survivors. Moreover, it was also be the third leading cause of death in developed countries (3). In general, disabilities of patients with stroke consist of inability to control movement, language understanding and thinking, memory, sensory, and emotional disturbances (5-7).

There are several changes appear in patients with stroke involving the muscle strength, muscle tone, sensation, and balance control. Several reports concluded that these changes may influence the potentials of patients (8-14). Walking is one of complex movements which require the co-ordination of both legs and interaction of a large number of muscles and joints to function together (15). It is the important task which stated as a goal in rehabilitation (16-18). Gait disturbances, such as slower walking velocity, laborious, uncoordinated, and asymmetric gait pattern are usually observed in patients (7, 18-23). Hemiplegic subjects tend to move their limbs relying on synergies of mass flexion and extension patterns. Moreover, inability to differentially control agonistic and antagonistic muscles, poor gross- and fine-motor control, and movement timing also occurred (24, 25). These abnormal characteristics can be observed with the alteration of temporo-spatial, kinematics, and kinetics data (26-29).

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Typically, temporo-spatial variables in the stroke are reported as decreased gait speed, stride length, step length and increased step width when comparing to normal healthy subjects (20, 28, 30-33). Considerably shorter single support time than double support time also occurred as a result of decreased muscle strength. Unequal time consumption for both limbs are presented with longer swing time and shorter single support time in the affected side than the un-affected side (30). Kinematic data of hip, knee, and ankle have been studied (5, 21, 26, 34, 35). There were many differences of angular displacement between the stroke and able-bodied subjects. Decreased hip flexion during swing period occurred. It resulted in compensatory movement of hip with abduction and external rotation both during stance and swing phases (26, 35). The deviation patterns of knee movement in the stroke frequently showed no first knee flexion wave, mild knee valgus during mid stance phase, and marked deficiency of knee varus during swing phase (21). At the ankle, lack of dorsiflexion and plantarflexion movements frequently happened.

However, these albeit pattern usually have been investigated on the affected side only, Olney et al in 1994 (28) stated that the information gained simultaneously from both sides might yield more the explanations of walking. The question surrounding gait symmetry and there role in gait should be addressed. Thus, information of the two sides of the body would be helpful in understanding the nature and degree of the compensatory mechanisms in patients.

A common observation among the stroke subjects during stance and locomotion was uneven weight bearing distribution (36). Both magnitude and shape of ground reaction force in the stroke showed significant differences from those of able-bodied (37). Gait speed usually determined gait performance (26, 38-44). It was reported that gait speed was positively related to the stage of lower extremity recovery (9, 45, 46). The advantage of gait speed was it is easy to detect in clinical setting (13, 28, 38, 40, 41, 45). However, gait speed cannot indicate the quality of walking. Other critical factor in gait performance is symmetry of gait pattern (37, 47-50). In healthy individual, gait pattern with respect to time, distance, and vertical force are fairly symmetrical deviation by only a small percentage from perfect symmetry (37). In

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contrast, stroke subjects showed marked gait asymmetry variables (48, 49, 51, 52). Therefore, the reduction of asymmetrical characteristics is one of the ideal objective in functional rehabilitation in the stroke (37, 49, 52).

In clinic, the prediction of the natural recovery or the potential effect of a given therapy is challenge to the rehabilitation specialists. Initial severities of the stroke (25), motor function (16, 31, 33, 53, 54), spasticity (25, 40), sensation (25, 55), age (56), and leg strength (9, 45, 46) were analyzed as the predictors of functional outcome and independent ambulation. Nadeau and co-workers in 1999 (38) identified the most important variables determining gait speed in the stroke. The results revealed relationships between gait speeds both in comfortable and maximal speeds and motor function of lower limb, balance, and strength of hip flexors. Nevertheless, the association of other physical impairments (plantarflexors strength, sensation, and muscle tone) was not found. In chronic stroke subjects, it was found that hip flexors strength was the major factors predicting comfortable and maximal safe speeds (28). In clinic, lower extremity muscle strength can be expressed in function with ordinal scales as a Fugl-Meyer scale (57, 58). This motor control assessment scale was widely used and was demonstrated to have high intra-reliability (59). It also reported as one of variables which related to gait performance (16, 31, 33, 53, 54).

Another determinant contributing to walking performance is spasticity, an increase or exaggeration of the stretch reflexes. Gastrocnemius is the multijoint calf muscle which flexes the knee and plantarflexes the ankle. During single support phase, foot remains flat on the ground and the shank rotates forward. Consequently, the gastrocnemius muscle is stretched at the end of its range. Ada and co-workers in 1998 (11) examined the contribution of spasticity in the gastrocnemius muscle to walking dysfunction of subjects with stroke. The results showed that two-third of the stroke subjects exhibited spasticity. However, their findings were that even when stroke subjects exhibited abnormal tonic stretch reflex activity under relaxed condition, their tonic stretch reflex was not different from control subjects. These outcomes may be due to the variation of subjects which have stroke at the first time but ranged from several months and several levels of spasticity. In addition, the spasticity of other part

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such as knee extensor muscle reported no significant correlation with gait speed (12, 13). From the past studies, relationship between spasticity of ankle plantarflexors or knee extensors and gait speed was established solely, when the competence of walking required several muscles to achieve. Consequently, it is interested to determine other lower extremity muscle tone which may influence gait performance. For sensation, Brandstater et al in 1983 (33) reported no relationship between sensory appreciation and locomotion. Their results concluded that motor recovery was more important than sensory appreciation in gait performance. However, Kang et al in 2002 (25) reported that hemiparetic subjects who had intact proprioceptive sensation showed significant faster walking velocity, longer stride length, and less stance time than patients with impaired proprioception.

Despite these findings, the relationship between many clinical measurements and gait performance variables is not sufficient because some muscles and parameters were selected. Selection of the appropriate variables in gait characteristic is critical for intervention assessment. To provide a guideline for standard rehabilitation measurement, it should be verify on two important comparisons that predominate in rehabilitation. First, individuals with stroke movement need to be compared with normal performance. The lower limit of normal performance can be established and used as a criterion for comparing individual patient. Second, it is important to evaluate changes in the stroke relatively to typical pattern occurring in other patients. This information will be beneficial for determining the degree of expected improvement in patient undertaken rehabilitation (33).

Shummway-Cook and Woollacott in 1995 (60) pointed out that it should be considered the interaction of individual, task and environment in motor control study. According to this point of view, the investigation of movement in patient with stroke during different walking speeds is necessary to understand how patient perform this challenging context. In general, changes in gait speed required the adjustment of a neuromuscular gait factor (61). Up to date, little is known about the stroke subjects' capability of adapting to the demands of speed, depending on their initial functional performance. In addition, less details about the comparisons of the gait biomechanics

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between able-bodied and the stroke during different speeds was reported (62). Most reports studied only on the sagittal plane at the comfortable speed (28, 63) and interpreted the findings based on descriptive explanation (26).

Faster gait speed and better gait appearance are perceived by patients post stroke as their ultimate goal of rehabilitation. To enable theses patients to achieve the goal, therapists should identify the underlying impairments that account for the deviated gait characteristics as reduction and asymmetry of gait. Impairments of muscle strength and tone, motor control, balance, and sensory have been suggested to be related to the inability of hemiplegic patients to walk in normal fashion (12-14, 25, 54, 64). However, the impairments that are the most important factors that related to gait performance in terms of speed and symmetry of this group of patients remain unknown. As well as the important question in the study of motor control in the movement of pathological condition relating to the compensatory mechanism adaptation during different speed of walking should be established. Therefore, it is interesting to find out the significance compensatory strategies using during gait comparing with increased gait speed conditions. The understanding of these abnormality movements will allow more information of properly treatment plan. The identification of abnormal characteristics with three dimensional analysis and determination in the relationship between clinical and laboratory gait parameters are necessary in stroke rehabilitation.

Purposes of the Study

General Objective

This study determined the relationships between clinical measures (muscle tone, lower extremity motor function, and postural balance) and gait performances (gait speed and symmetry). In addition, comparisons of biomechanics data at the comfortable and fast gait speeds between the control and the stroke and between the affected and un-affected sides of the stroke were investigated.

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Specific Objectives

1. To determine the relationships between clinical measures (muscle tone, lower extremity motor function, and postural balance) and gait performances in the patients after stroke.
2. To compare biomechanics data at two gait speeds (comfortable and fast) between the control subjects and the patients after stroke.
3. To compare biomechanics data at two gait speeds (comfortable and fast) between the affected and un-affected sides of the stroke.

Parameters

The following parameters were investigated;

- Laboratory parameters

1. Temporo-spatial data

1.1 Parameters comparing between the control and the stroke

1.1.1 Cadence (steps/min)

1.1.2 Double support time (DST) (s)

1.1.3 Step width (m)

1.1.4 Stride length(m)

1.1.5 Stride time (s)

1.1.6 Gait speed (m/s)

1.2 Parameters comparing between the affected and un-affected sides of the stroke

1.2.1 Single support time (SST) (s)

1.2.2 Step length (m)

1.2.3 Step time (s)

2. Kinematic data of the hip, knee and ankle joints in the sagittal, frontal and transverse planes composed of;

2.1 Angular displacement (degrees)

Angular displacement of the hip, knee, and ankle joints were compared at the initial contact (IC), midstance (MS), and toe off (TO) events of the gait cycle.

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2.2 Angular velocity (degrees/s)

Five peak angular velocities of the hip, knee, and ankle joints composed of;

2.2.1 Hip velocity during the initial swing (H)

2.2.2 Knee velocity during the initial swing (K1)

2.2.3 Knee velocity during the terminal swing (K2)

2.2.4 Ankle velocity during the initial swing (A1)

2.2.5 Ankle velocity during the mid swing (A2)

3. Kinetic data composed of;

GRFs in the medio-lateral (F_x), antero-posterior (F_y), and vertical (F_z) directions (%BW). GRFs were analyzed during stance phase of gait with the following variables (see Figure 1);

3.1.1 GRFs in the medio-lateral force direction (Fx)

- 1st peak lateral force (X1)
- 1st peak medial force (X2)
- 2nd peak medial force (X3)

3.1.2 GRFs in the antero-posterior force direction (Fy)

- Braking peak force (Y1)
- Propulsion peak force (Y2)

3.1.3 GRFs in the vertical force direction (Fz)

- 1st peak vertical force (Z1)
- 2nd peak vertical force (Z2)

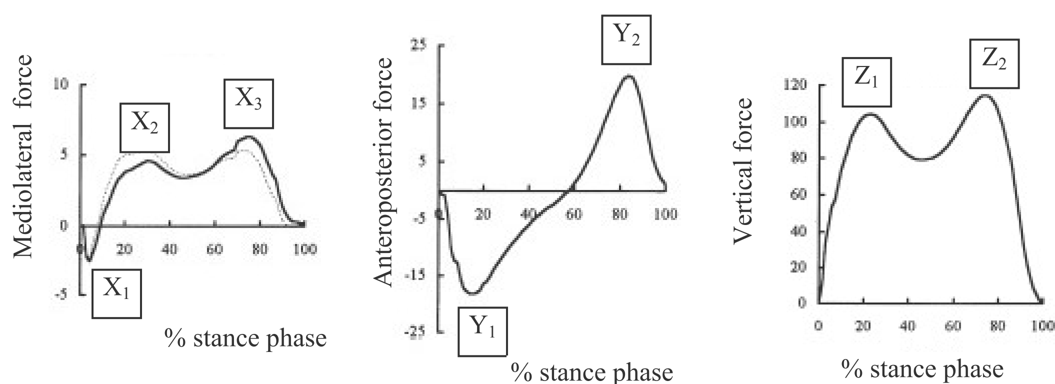

Figure 1.1 Ground reaction forces acquired from normal gait data.

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4. Gait symmetry

This study investigated gait symmetry of vertical GRF (%BW), single support time (s), step time (s), stance time (%GC), and swing time (%GC) of comfortable and fast speeds. Gait symmetry was determined by symmetry index (SI) (%) with the following equation (50);

$$SI = \frac{(V_{affected} - V_{un\text{-}affected}) \times 100\%}{1/2\ (V_{affected} + V_{un\text{-}affected})}$$

After that, the relationships of gait symmetries and clinical measures were determined.

- Clinical measures

1. Modified Ashworth Scale (MAS) determined five lower extremity muscle groups including the hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors muscles.

2. Fugl Meyer Assessment of lower extremity Scale (FMA) determined the lower extremity motor function.

3. Berg Balance Scale (BBS) determined the postural balance performance.

Scope of the Study

First, this study determined the relationship between clinical measures (muscle tone, lower extremity function, and postural balance) and gait performances (gait speed and symmetry) in the patients after stroke. Second, gait characteristics between the control subjects and the patients after stroke and between the affected and un-affected sides of the stroke were determined.

Hypotheses of the Study

1. There were no significant correlations between clinical measures (muscle tone, lower extremity motor function, and postural balance) and gait speed, and between clinical measures and gait symmetry in the stroke.

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2. There were no significant differences in biomechanics data between the control and the stroke at two gait speeds (comfortable and fast).

3. There were no significant differences in biomechanics data between affected and un-affected sides of the stroke at two gait speeds (comfortable and fast).

Clinical significances

1. The results of this study provided the information about the degree of relationship between clinical and laboratory gait characteristics in the stroke.

2. The information led more understanding about three dimensional gait characteristics of the stroke explained by the kinematics and kinetics information of the affected and the un-affected sides.

3. The results provided information and knowledge of the primary abnormality, compensatory mechanism, and common deviated pattern of gait in the stroke.

4. The results provided the information of differences of the biomechanic characteristics between the control and the stroke which were useful for the treatment plan in stroke.

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CHAPTER II
LITERATURE REVIEW

2.1 Normal Gait

Human gait is a form of periodic motion of the legs which involves several joints co-ordination such as the hip, knee, and ankle (65, 66). A remarkable ability to control hip, knee, and ankle co-ordination assists in minimizing the vertical displacement of center of mass (COM). Hence, these muscles which attach at various parts along the skeletal supporting structure perform more than one function during gait (67-69). A normal gait is considered as a repeatable and reproducible in each individual. Beyond the differences manifest during walking, there are quite consistent pattern shown within a normal range which be examined from much of biomechanical variables (70). Most researchers consider the inter- and intra-individual variations in normal gait to also be small. Based on small inter- and intra-individual variation assumptions, there has been extensively effort in establishing references of typical parameters for normal gait to use as a reference when comparing with pathological cases (62, 70).

A stride or one complete gait cycle is defined as a set of movements and events which take place between two successive initial contact with the ground of the same foot (2, 71, 72). Two principal phases of the gait cycle can be divided into the stance and swing phases of each leg. When focusing on one leg, the stance phase is the period when the foot is in contact with the ground while the swing phase begins when the foot leaves the ground. At the comfortable gait speed, stance phase takes place about 60% of gait cycle and the remaining 40% gait cycle is the period of swing phase. These percentage of the stride can varied with the changes of gait speed (73). Stride length is the distance between two successive heel contacts of the same foot, while step length is the distance between two successive heel contacts of the different foot (2, 72). Stride length and step length should be equal for the left and the right steps in general (73). The stance phase can be further divided into single limb and double limb

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supports according to the amount of limbs used to support the body (2, 71, 72). An application of terminology to pathological gait events requires modification. Generic terminology can be applied to both normal and abnormal gait and was developed by clinicians from the Pathokinesiology and Physical Therapy Department at Rancho Los Amigos Medical Center. The gait cycle are classified to eight events, five gait events for the stance phase and three gait events for the swing phase. At the stance phase, five gait events are initial contact, loading response, midstance, terminal stance, and preswing. And at the swing phase, three gait events are initial swing, midswing, and terminal swing (74). Gait cycle can also be analyzed according to whether one or both feet are in contact with the ground. The double support time is the period of time during which both feet are in contact with the ground. When increasing gait speed, double support period will decrease and disappear while running. Single support time is the period of time during only one foot contacting with the ground and is the period of time which the contra-lateral limb swings concurrently (73).

2.2 Prerequisites of Normal Gait

The requirements of normal walking have been stated with many aspect of field. Two major abilities which are essential in normal walking include equilibrium and locomotion. Equilibrium is the ability to assume an upright posture and maintain balance. Locomotion is the ability to initiate and maintain rhythmic stepping. However, many additional contributing factors may be involved. For example, the musculoskeletal system must provide the intact bone and well functioning joints as well as adequate muscle strength. Muscle weakness has important consequences in the older people. Lower limb muscle weakness, in particular, is reflected in reduced general mobility (75-77). According to the system model, balance and mobility functions are maintained by cooperative interactions among the biomechanical, musculoskeletal, sensory and central nervous system components. When impairments is limited to a single component, the impact on overall function frequently is masked by the compensatory actions of the other healthy components. The interaction of multiple sensory, motor, and integrative systems influence to balance. In particular, balance depends on contributions from vision, peripheral sensation, vestibular sense, muscle strength, neuromuscular control and reaction time (78).

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For the biomechanics aspect, Higgins and Higgins in 1995 (79) identified three critical features during walking. It included the displacement of the body COM in forward direction, the regaining of control during the resistive phase, and establishing the successive base of support. Disturbances of walking resulting from some motor dysfunction might be considered in terms of an ability to solve one or more sub-goals of the task. Four sub-goals were identified in walking with assistive walker. Each sub-goal has counterpart the prerequisite and the critical biomechanic features which are the prevention of the lower limb collapse, maintenance of postural support of the upper body, maintenance of the equilibrium during the double and single support periods, and controlling the foot trajectory for the safe ground clearance and gentle initial contact. For satisfactory execution of bipedal locomotion, all requirements must be coordinated simultaneously and continuously.

When consider the functional goals of human ambulation, it included the achievement of success moving from one place to another place, moving safety, and moving efficiency (73). The efficiency of walking has been studied based on the principal of minimizing energy consumption (80-82). Energy consumption and the determinants such as gait symmetry and gait speed are widely used to describe and evaluate the gait pattern both in normal and abnormal cases (19, 41, 47, 49, 50). The gait cycle comprises several major requirements for the successful stance and swing phases. Lower limbs play a significant role in these requirements. In the stance phase, it includes supporting, propulsion, balance, and absorption function. In the swing phase, the foot moves on a smooth path from toe-off to heel contact, the lower limbs are involved in toe clearance and foot trajectory for preparing the foot for a safe landing (15).

Assumption of symmetry in human gait has been proposed by means of maximizing the energy efficiency (83). Griffin et al in 1995 (48) and Hesse et al in 1997 (47) suggested that the term of 'gait symmetry' were used when there is no statistical differences noting on bilateral parameters. Anatomical and physiological aspects have also described the symmetrical is the normal behavior. The parameter which frequently demonstrated symmetry in normal gait was temporo-spatial

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characteristics (37, 84, 85). In addition, the characteristic of COP and COM when initiating was not difference between left and right side in normal (47). Other common means of determining symmetry in gait is the assessment of GRF data (37). Goble et al in 2003 (83) investigated symmetry of peak and temporal GRF in the vertical and antero-posterior directions in 20 able-bodied in three different gait speeds, they suggested that symmetry can maintained among different gait speeds and support to the previous published that walking is a full symmetrically task. In elderly, symmetrical study was also reported by Sadeghi, Prince, and Zabjek in 2004 (85). By comparing the both left and right lower extremity muscles work with 3D method, they found that the peak muscle power were similar between two side in the sagittal plane, except only the hip extensors.

During the stance phase of gait, Perry in 1992 (67) proposed that the function of the supporting limb is act as a generation of propulsive force, maintaining upright stability during static and during changing posture. Minimized the shock of floor impact when the foot is in contact with the ground at the early stance phase, and conserved energy in a manner of reduces the amount of muscular effort are also necessary.

2.3 Gait Biomechanics

2.3.1 Gait kinematics

Kinematics is the subdivision of mechanics that deal with the geometry of motion without regard to the force causing motion. It relates to the relatives of displacement and time. Kinematic variables include the trajectories of single segment, angular displacement, velocity, and acceleration (71, 72, 86).

2.3.1.1 Center of mass (COM)

In normal standing, vertical center of mass (COM) or center of gravity (COG) locates in the midline, 1 inch anterior to the second sacral segment and about 55 percent of the body height in adults. In comfortable gait speed, vertical COM moves upward and downward within the base of support. Vertical COM curve displaces smooth and sinusoidal to the plane of progression. The peak oscillations of

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vertical COM appear at approximately 25 and 75% gait cycle, corresponding to the midstance phase of each supporting limb. The lowest point of vertical COM attains corresponding to the point in time of both feet are in contact with the ground or at the double support phase. There is also the lateral oscillation of the COM in the horizontal plane. Displacement of lateral COM has smooth sinusoidal curve and presents about one-half the frequency of the vertical displacement. The peak lateral COM oscillation is corresponding to the stance phase of the ipsilateral limb. Therefore, this peak lateral COM displacement displaces corresponding to the peak vertical COM displacement (65, 70). In normal, gait is characterized by a periodic vertical displacement of the COM that moves through a complete cycle of vertical motion with each step. The peak-to-peak amplitude of the vertical COM displacement, referred to as the vertical excursion, is generally regarded to be about 4–5 cm for adult at their comfortable gait speed (65). Many investigators have been used the vertical COM motion during walking to estimate the mechanical energy changes, to gauge efficiency and work, to describe symmetry, and to indicate quality of gait both in normal and pathologic cases (81, 87-90).

2.3.1.2 Trunk and pelvis motion

Trunk and pelvis rotates in opposite direction simultaneously when walking. The opposite direction horizontal movement produces smooth and efficient progression of the COG through a counterbalance mechanism (70). In normal walking, the pelvis is tilted downward relative to the horizontal plane on the side opposite to that of the weight bearing limb. The angular displacement of pelvis is on average of 5 degrees (72). Gard and Childress in 1997 (91) measured effect of pelvic tilt on the vertical displacement of the trunk during normal walking. Pelvic tilt found to be maximum at approximately during the toe off and nearly neutral at the midswing periods for freely-selected gait speed. Moreover, the pelvic tilt has significantly less influence on the vertical excursion of the trunk across the range of typical comfortable gait speed which is expressed approximately 1-2 m/s.

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2.3.1.3 Arm swing

Human bipedal stance and gait requires a strong and effective neuronal inter-limb co-ordination between legs. However, an inter-limb co-ordination exists not only between leg muscles but also between the arms during a great variety of manipulative tasks (92). Dietz et al in 2001 (92) studied the neuronal co-ordination of lower and upper limb muscles. The observations suggested the existence of a flexible neuronal coupling between lower and upper limb muscles. In normal walking, the presence of arm swing during the phase of contra-lateral limb moves assist in efficiency of walking progression. Correct arm swing assists the generation of corrected trunk rotation, therefore a more efficient gait pattern occurred (70).

2.3.1.4 Hip motion

Kinematics of hip motion in three planes involves the relative motion of pelvis and femur in 3 degrees of freedom. Normally, there is 41 degrees of hip motion in the sagittal plane, 9 degrees of coronal plane motion, and 12 degrees of transverse plane motion. The sagittal hip motion is observed as a single sinusoidal curve. At heel strike, hip is at the maximum flexion and being extended just after the early stance phase. The hip extends through foot flat and near 0 degree flexion at the time of heel off. After that, the hip continues extend through heel rise and push off. Maximum hip extension is reached and then flexion begins just before the toe-off. The hip will flex throughout swing phase and reaching maximum flexion again before the heel strike (70-72). In the coronal plane, the hip is in the neutral or slightly abduction at the time of heel strike. Hip adduction occurs through foot flat and heel off, reaching maximum adduction at 80% of stance phase period. At the late stance, there is an abduction which reaching its maximum immediately after toe off (70-72). In the transverse plane, there is an external rotation of the hip briefly before the heel strike and it remains in external rotation in the early stance phase. Internal rotation then occurs after that and progress the maximal internal rotation at the time of toe-off. Hip then rotates externally again during swing phase. Prior to heel strike, hip will rotate internally for the preparation of weight acceptance (70-72). Hip motion during gait may be summarized as extension, adduction, and internal rotation during the stance

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phase. Additionally, hip flexion, abduction, and external rotation are generated during the swing phase (70-72).

2.3.1.5 Knee motion

Movement of tibia relative to the femur takes place in three planes. Normally, there is 70 degrees motion in the sagittal plane, 0 to 12 degrees of frontal plane and 13 degrees motion in the transverse plane. In the sagittal plane, the knee is slightly flexion at the heel strike. During the early of stance phase, knee flexion is accentuated about 20 degrees. As the body is progression over the foot, from flat foot until heel off, knee is extended. Then, knee flexes immediately after heel off and continues during the early swing phase and reaches maximum extension just before heel strike. In the coronal plane, adduction of 5 to 10 degrees occurs at the heel strike and remains essentially stable through the foot flat. Knee slightly abducts during the second half of the swing phase. In the transverse plane, knee is externally rotates at the heel strike. In the early stance phase, as the knee flexes, it is also rotates internally. As the knee extends at the heel-off, the tibia rotates externally simultaneously. During the swing phase, the knee will external rotate while the knee is flexed (70, 72).

2.3.1.6 Ankle and foot motion

Tibiotalar motion occurs primarily in the sagittal plane with the motion of ankle plantarflexion and dorsiflexion. When subtalar and midtarsal motion is included with the tibiotalar motion, 3 degrees of freedom is noted. At the heel strike, there is initial ankle plantarflexion to place the foot on the ground. From foot flat to heel-off, there is dorsiflexion when body moves over the foot and followed by rapid ankle plantarflexion associated with push-off. During the swing phase, ankle dorsiflexion brings the ankle back to neutral. It is therefore the foot will clear the floor and be prepared for the next heel strike. The subtalar joint is in supination at the heel strike and quickly pronates to the foot flat, while at the heel-off, supination occurs again. The foot is a rigid lever in the supinated position at the heel strike and push-off events, and is a mobile adaptor in the pronated position at the foot flat event. The floor foot contact pattern is quite consistent, observed in the healthy subjects. The heel makes the initial contact and usually contact with the floor for 55% of the stance

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phase. The area under the fifth metatarsal head makes contact with the floor from 15 to 85% of the stance phase. The first metatarsal heads area closely follows the fifth, making contact at 20%, and finally, leaving the floor at 95% of the stance phase. The toe area makes contact with the floor at about the time the heel leaves the floor, or 55% of the stance (70).

2.3.2 Gait kinetics

Kinetic is the study of relationship between the forces and the resulting motion (72, 86). Kinetic variables in gait have been studied involves the ground reaction force (GRF), net joint moment (NJM), and net joint power (NJP). The critical kinetic tasks during the stance phase of gait was summarized by Winter and Eng in 1995 (93). Firstly, maintaining balance of the large load of the upper body when moves forward on the hip joint and preventing vertical collapse of the body and also contribute energy to forward progression of the body. Secondly, the large number of segments involved in a movement that simultaneously involves the stance and swing limbs.

2.3.2.1 Ground reaction force (GRF)

The ground reaction force describes the reaction force provided by the support surface on which the movement is performed. It is derived from Newton's law of action-reaction to represent the reaction of the ground to the accelerations of all the body segments. GRF is detected by the force platform which is an instrument commonly used in gait analysis. It gives the total force applied by the foot to the ground. Some force platforms give only one component of the force usually is the vertical component, but most force platforms give a full three-dimensional description of the average ground reaction force vector. The electrical output signals are processed to produce three components of force which are the vertical, medio-lateral and antero-posterior forces, the two coordinates of the center of pressure, and the moments about the vertical axis. These components represent the reaction of the ground to the actions of the person that are transmitted through the feet to the ground and that correspond to the acceleration of the body in these respective directions. The extent of which any body segment influences the ground reaction force depends on its

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mass and the acceleration of its COM (94).

In normal walking, the vertical force shows a characteristic with a double hump. The first peak vertical force increases of about 112% body weight resulting from an upward acceleration of the COG during the early stance. Vertical force curve drops to about 93% body weight during the midstance period and then increases again to about 110-115% body weight due to deceleration as the downward motion is checked in late stance. After the final peak of vertical force the force drop down rapidly for the preparation of foot to leave the ground. The fore-aft or antero-posterior force, at the heel strike contact, the force goes to backward for the braking force during the first half of the stance phase. Then, pattern reverse to the opposite direction for the acceleration force to propel body forward during the second half of stance period. This antero-posterior force exhibits deceleration and acceleration cyclical smooth pattern during walking. The medio-lateral force is small, it first begins with the minimally lateral force and then towards to the medial force (70, 95).

2.3.2.2 Net joint moment and power

Joint moment can be defined as an effect of the force and the function of muscle which is almost invariably to produce moments at joints. Therefore, changes in muscle function and control are commonly manifested as changes in joint moment. The parameters which must be measured to estimate the net joint moment are the segmental anthropometry, accelerations, lever arms, and the GRF (96, 97). Net joint moment is expressed with the net moment of force at the joints. Predominantly agonistic or antagonistic muscle groups provide the data at a specific event. Net joint power is the product of a net joint moment and the joint angular velocity. Joint power is generated when the moment and the angular velocity are in the same direction and is absorbed when they are in opposite directions. This mechanical power is only single variable in biomechanical data which reveals the role of muscles in propelling and controlling movement during gait (96, 98, 99).

In normal, muscles generate a positive hip power at loading response when hip extends and again at the end of stance when it flexs (96). Both of

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these periods are characterized by concentric muscle contractions. In contrast, the knee has only a brief period of power generation, producing only a small amount of power. Hip flexors generate considerable positive power at the end of stance. Then, the ankle plantarflexors generate a large positive power at pre-swing period. These data suggested that the hip flexors and hip extensors and the ankle plantarflexors contribute important energy to lower limbs during normal locomotion (97, 100).

2.4 Hemiplegic Gait

2.4.1 Definition of stroke and prevalence

Stroke, defined by WHO (World Health Organization), is an acute neurological dysfunction of vascular origin with sudden occurrence of symptoms and signs corresponding to the involvement of focal areas in the brain and the symptoms more than 24 hours (1, 2). A great number of the incidence and mortality from cardiovascular disease in Thai populations was reported from Ministry of Public Health in 2002. At present, it was found that the cardiovascular disease is the major disease leading to disability and handicap (4). Approximately, two-thirds of acute hospitalized stroke patients cannot walk independently (17). Of those individuals who recover their ability to walk, many are still disabled by slow gait speed and limited endurance, which restrict their independent mobility at home and in the community. Stroke is a common disease with high mortality and high incidence of disability and handicap among survivors. They exhibit varying deficits in perception, muscle strength, motor function, passive mobility, sensation, muscle tone, and balance (5-8, 10, 11, 101). These impairments have significant effects upon walking ability. The exact combination of the impairments depends on the extensiveness and location of the brain damage (3, 53).

2.4.2 Hemiplegic gait characteristics

Gait pattern of hemiplegic subjects is characterized by slow, laborious, un-coordinated limb movement. A lack of selective joint control and co-ordination of intra-limb and inter-limb co-ordination during walking often occurred in stroke (102, 103). It was replaced by mass limb movement patterns or synergy pattern on the affected side and requiring the compensatory movement of the other parts (31, 104).

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Reduced weight bearing on the affected limb also commonly found in stroke (19, 37, 47, 49). Smooth and symmetric forward progression of the body is impaired with a large variation in gait patterns related to the degree of recovery (17, 29, 31, 105-107). Compensatory movements necessary for ambulation produce the abnormal displacement of the COG, resulting in increased energy expenditure and unco-ordinated muscle function (31, 108-110).

Previous studies have been reported that altered kinematic and kinetic gait profiles in both magnitude and pattern (shape and direction of curve) often found in patients with stroke. These abnormal gait profiles indicated an impaired ability to generate and grade the forces that control limb movement. Deviation to normal gait patterns can be observed during both swing and stance phases in the sagittal, coronal, and transverse planes (16, 28, 30, 43, 49, 111-115).

Because of stroke populations is a heterogeneous group. Severity and type of stroke caused a large extent the symptoms and outcome. Therefore, the stroke who eventually regains recovering of walking ability may have great differences in gait speed, temporo-spatial characteristic, kinematics, and kinetic gait patterns. Nevertheless, numerous studies attempted to classify hemiplegic gait patterns and appears that some specific movement patterns can be observed in sub-groups of patients (21, 107, 116-118). The average gait speed of stroke patients is lower than that of healthy controls but the results expressed vary depending on the severity of the stroke, time post-stroke, age of the subjects, and others (24, 115, 119). Although the gait pattern in subjects with hemiplegia varies among subjects, the typical characteristic is described in clinic. Perry in 1992 (67) suggested that the typical abnormality observed in hemiplegic gait come from poor single limb balance as well as difficulty controlling forward progression. Subjects with hemiplegia lack of 1) adequate shock absorption at heel strike, 2) control of momentum during stance, 3) the ability to generate force for pushing off to maintain body forward, 4) quick adequate excursion of the affected limb during swing.

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Gait problems in patients with stroke are very complex and almost individually. Although the general characteristic of hemiplegic gait have been identified with the large differences, recent biomechanic researches have been provided the insight mechanism and reasons underline that abnormal movement which are very useful and necessary in practice (62).

2.4.3 Abnormal function of hemiplegic gait

2.4.3.1 Abnormal base of support

The normal walking base is usually in the range of 50-100 mm. In patient with stroke, it may be either increased or decreased beyond this range. Wide walking base of support may be caused by any deformity, such as an abducted hip or valgus knee. Increased lateral movement of the trunk is also required to maintain balance. The other important causes of an increased walking base are instability and fear of falling. The feet are placed wide apart to increase the area of support. This allows a margin of error in the positioning of the center of gravity over the feet. A narrow walking base usually results from an adduction deformity at the hip or a varus deformity at the knee. Hip adduction is commonly seen in the cases who have considerable spasticity of the lower limbs (95).

2.4.3.2 Abnormal foot contact

Inappropriate foot contact results in instability of the whole body. Common causes of abnormal foot contact resulting from equinovarus posture which often happens in hemiplegic patient. This abnormal posture may result in an unstable base of support during the stance phase of gait. Ground contact with forefoot and weight dominantly on the lateral part of the foot are also results in instability. Limitation of ankle dorsiflexion and prevention of forward progression of the tibia over the stationary foot, causing knee hyperextension and interference with the terminal stance and preswing events where lack of propulsive force was noted. Other causes of an abnormal base of support include the excessive toe flexion or extension during stance phase (73, 95).

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2.4.3.3 Abnormal limb stability

Stability during locomotion is maintained through reactive, predictive, and anticipatory strategies and involves the control of COM position and velocity within the changing and moving base of support (120). Sensory information assessing the position and motion of the body in space is processed through the sensory system includes the visual, somatosensory, and vestibular systems (121). Sensory information from these three modalities, knowledge, and prior experience are play a critical role in the control of dynamic stability (120).

There are two biomechanical disadvantages that make walking is an especially challenging task (77). Gait instability may arise in particular the two single limb support periods. During the single limb support, the body is in an inherent state of instability because the vertical projection of the center mass passes along the medial border of the foot and not within the base of support. In addition, the two periods of single limb support are relatively long and spend the time for 75 to 80% of the whole gait cycle in general (72). The period of stability is only occurs during the double limb support which is two feet are in contact with the ground and occupy in the remaining period of time.

Considering in the segmental control, knee flexion during early stance phase often produces limb instability in patients with stroke. Limb instability is more common in the early phase of recovery in stroke (73). In the early recovery phase, flaccidity and muscular weakness affect on the affected side in patient with stroke (73). Consequently, patient in this phase frequently unable control the selective movement of the hip, knee, and ankle joints. Excessive knee flexion and extension usually happen during the gait cycle (95). Knee hyperextension during the stance phase is the results of spasticity of ankle plantarflexors, ankle plantarflexors contracture, and compensation of knee weakness. These abnormal postures of the knee also prevent an adequate contralateral limb advancement (73, 122). Hip flexion during stance phase is less common. When hip flexion occurs, trunk instability and significant interference with ambulation are produced. This problem is common in the early stage of recovery with flaccidity or in patients who have significant flexor synergy (73). Hip

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hiking and contralateral trunk lean are needed as a compensation for limb advancement and clearance in swing in patients who have limited joint flexion during swing (35, 95, 123).

2.4.3.4 Abnormal limb clearance

During the swing phase, limb clearance and advancement are occurred. When limb clearance is inadequate, limb advancement is usually compromised. The most common causes of limb clearance problem are lack of adequate hip flexion, knee flexion, and ankle dorsiflexion. Not only the total joint displacement, but also the synchronization of motion between the involved joint is essential to produce appropriate limb clearance (73). Stiff knee gait pattern is the most commonly observed in the spastic hemiplegic patient. Patient is unable to flex the knee adequately creating a large moment of inertia which increase the energy required to initiate the swing phase of the affected limb. This requires the patient to utilize ipsilateral hip and trunk and contralateral limb compensatory motions. Unable to flex the knee during the swing phase inhibits toe-clearance, resulting in the requiring of compensatory movements. The diminished knee flexion associated with stiff-knee gait is frequently attributed to abnormal activity of the rectus femoris muscle (124, 125).

In normal, knee flexion is essential during the swing phase for lifting the foot from the ground and advancing the limb. Rapid knee flexion for limb advancement is achieved during pre-swing and swing phase (124, 126). At the beginning of the swing phase, knee flexion with heel off occurred. After that, additional knee flexion is performed to facilitate foot clearance from the floor. The total knee flexion during swing is approximately up to 60–65°. Therefore, knee flexion is one of the essential motion to lift the foot for limb advancement (124, 126). Three mechanisms are used to achieve the necessary knee angle during swing phase are previous knee flexion reached during the preswing phase (40°). Then, momentum is initiated by rapid hip flexion and ankle plantarflexion which quickly advances the femur and active knee flexion by the knee flexor muscles (126).

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Inadequate hip flexion is also a cause of abnormal limb clearance. Nene et al in 1999 (127) studied the function of rectus femoris during the initial swing phase of ten normal healthy subjects when walking with slow and fast gait speeds. The results showed that rectus femoris and vastus lateralis worked independent of each other during the initial swing phase. The amount of rectus femoris activity was clearly related to gait speed. The muscle activity increased with increasing gait speed. The relationship between the angular acceleration of the shank and the amount of rectus femoris activity was linear. The active knee moment, as a function of the shank's angular acceleration, showed a high correlation to the EMG signal of rectus femoris.

2.4.3.5 Gait asymmetry

Asymmetrical steps are one of common characteristic of hemiparetic gait. The affected limb always has a shorter stance time and step length than that of the un-affected limb. It has been reported that the degree of asymmetry is related to the degree of motor recovery (23, 33, 43) and spasticity of the affected ankle plantarflexors (49, 128, 129). Abnormalities in standing balance and asymmetry during single-limb stance are assumed to be related to a decreased ability to bear weight on the affected side (49). The weight shift to the affected side is essential in walking as it allows the un-affected limb to move. Consequently, the step will be occurred appropriately. The ability to maintain single-limb support is an important determinant of gait stability (67). Therefore, single-support stability training assists in the achievement of more symmetrical gait pattern in stroke patients (115). Gait asymmetry leads to increased energy expenditure and risk of falls. Consequently, the improvement in gait symmetry may provide an important clinical detector of recovery and functionality (19, 48, 49, 52).

2.4.3.6 Abnormal motor control

Stroke patients who have poor selective motor control often walk with the synergistic mass patterns of the affected lower leg rather than the isolated joint movements (130). Simultaneous activation of the quadriceps with the gluteus maximus causes a mass extension pattern during the stance phase. The mass

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flexion pattern then causes synergistic contraction of the hip flexors, knee flexors, and ankle dorsiflexors during the swing phase (31). This primitive motor control produces the primitive patterned limb movement and inhibits normal progression during walking. It has been suggested that treatment strategies for stroke patients with poor motor control should focus on isolated and selected joint movement training to break up the mass synergistic pattern and improve walking pattern (31).

2.4.4 Abnormal gait biomechanics in stroke

2.4.4.1 Temporo-spatial

Although the spatiotemporal parameters are varying among normal subjects, these differences are less when compared with the differences within and among stroke subjects. Various temporospatial variables show differences between normal and stroke subjects. The most consistent difference reported is gait speed. Greater ranges of gait speed is reported in subjects with stroke than normal subjects (62, 73). Many studies have been documented that the stroke walked with a reduction of gait speed and cadence than normal (18, 30, 33, 49, 62, 73, 119, 131). They also had decreased stride length, step length of affected and un-affected sides, and increased step width (20, 28, 30, 33, 43, 115, 132).

The difficulty to maintain single limb balance, shifting weight support between limb, and spatiotemporal asymmetries are reported frequently by clinicians. There were also reports about swing/stance ratio in stroke subjects. Typically shorten stance time and prolonged swing time of affected side was shown when compared with normal subjects. Not only the affected limb was influenced, but also the un-affected side was deviated. To compensate the alteration of swing/stance ratio, the un-affected side of stroke subjects have an increased stance and decreased swing phase time. Consistent of these inter-limb compensations, periods of double-limb support were longer in stroke subjects than normal. Asymmetry steps are also the typical characteristic in hemiplegic gait, with the affected limb have a shorter stance time and step length than that of the un-affected limb. The degree of asymmetries were inversely related to the degree of motor recovery and positively related to gait speed (62).

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The abnormality of weight bearing on the limbs has also been noted, three differences in proportion of stance and swing periods were reported (23, 30). Firstly, the stance phase of both the affected and un-affected sides is longer in duration and occupies a greater proportion of the entire gait cycle in subjects with stroke than that of able-bodied subjects at normal speed. Secondly, the stance phase is both longer and occupies a greater proportion of the gait cycle on the un-affected side than on the affected side (33). However, the data compared between able-bodied and stroke at similar speed was little varied and significantly shorter on the affected side merely. Thirdly, a greater proportion of the gait cycle is spent in double support than that of able-bodied at normal gait speed. The total double support of stroke subject is significantly lower than that of able-bodied subject (23, 30).

Kuan et al in 1999 (30) studied the effect of cane used to gait characteristics. They found that walking with a cane had significantly increased stride time, stride length, affected side step length, and significantly decreased cadence compared with walking without a cane ($p < 0.05$). Although step width of stroke patients was greater than normal, step width was significantly decreased when walking with cane. Advantage of using cane was not only improving spatial characters, but also assisting the affected limb effectively to push-off and to shift the center of body mass toward the un-affected limb.

Obviously, the temporo-spatial variables are the most reliable and easy to measure. However, the necessity of obtaining other biomechanic parameters assists in identifying the mechanism of gait problems in patient (62).

2.4.4.2 Kinematics

Kinematic characteristics include linear and angular positions of the body movement. The interesting parameter is bound to the joint angle and their relationship to the event of gait cycle. The selected variables are the most relevant to perceived clinical problems and can be classified into two groups; the kinematics of the joints occurring at a particular instant of gait cycle and the maximum or minimum values during the relevant phase or gait cycle (115).

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There is considerable variability in joint kinematics pattern of the stroke subjects which greater than in the normal (62). From the review of hemiplegic gait by Olney and Richards (115), they concluded that kinematic pattern of hemiplegic gait can be classified with a combination of the following. Firstly, a reduced hip joint angle amplitude in the sagittal plane, caused by a decreased hip flexion at the heel strike and a decreased hip extension at the toe-off. Secondly, reduced knee joint angle amplitude caused by increased knee flexion at the heel strike and decreased knee flexion at the toe-off and during the swing period. Thirdly, increase in ankle plantarflexion at the heel contact usually leads to secondary compensations in other body segments. Many compensatory movements always occurred according to these deviated movements. It was found that the subjects with hemiplegia exhibited a wide variety of pattern caused by a different compensation movement.

For instance, hip circumduction may be occurred as results of reduced hip flexion and knee flexion during the swing period (31, 35, 118, 124, 133, 134) Limited ankle dorsiflexion is of particular concern with limited knee flexion which always happen during swing period contributing the apparent increased length and also resulting in hip circumduction (62). Stiff legged gait pattern is frequently reported as characteristic of limb movement in subjects with stroke. The causes of reduced knee flexion in stiff legged gait pattern came from the abnormal function of the quadriceps, including impaired dynamic hip flexion (135, 136) and impaired ankle control during gait (133).

Olney et al in 1991 (22) studied the characteristics of 30 ambulatory subjects with stroke. Group of subject was divided into three groups according to gait speed which are fast, medium, and slow. The results showed no significant difference of excursion between sub-group. In addition, inter-subject pattern of angular motion of affected and un-affected sides present rather similar. However, the different of hip, knee, and ankle magnitude between affected and un-affected sides was found.

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There are several patterns of hip, knee, and ankle expressed in hemiplegic gait. These substantial variability characteristics happen due to individual mechanism which has been detected by gait biomechanics variables (26, 113, 115). However, beyond the large variability existing in patients with stroke movement, consistent abnormality detected has been noted (73). The stance phase abnormality includes forefoot or flat foot initial contacts rather than heel contact (62). In addition, ankle inversion may be occurred and causing the lateral border of the foot to contact to the ground. In the early stance phase of gait cycle, inappropriate knee control may be noted. Knee hyperextension commonly occurred rather than slightly knee flexion with continued equinovarus of the ankle during the midstance (80, 126). Lack of hip extension may results in a shorter stride length and decrease in gait speed. Rapid ankle plantarflexion which normally occurred during push off was reduced or absent (63, 137). During the initial swing, inadequate hip and knee flexion may result in toe drag. The swing phase was frequently initiated by flexion of the entire limb rather the by smooth sequential movements of the thigh, shank, and ankle segments (21, 23). During the midswing period, a major problem is the insufficient dorsiflexion. During the terminal swing period, inability to perform co-ordinated hip flexion and knee extension produces a shortened step length which may be further complicated to insufficient ankle dorsiflexion (73). The knee and ankle extended simultaneously and abruptly in the late swing, rather than the normal knee extension with ankle dorsiflexion pattern used in preparation for heel strike.

To investigate the full gait characteristic especially in patients with stroke, most gait studies have been described the range of angular displacement at each joint throughout the gait cycle or at the specific part during gait cycle (115, 138). Moreover, it is necessary to obtain the information about how these variables are co-ordinated among joints in both affected and un-affected limbs (115, 134). The deviation of movement in stroke does not exist in only the affected side but also can be happened in un-affected side. Kerrigan et al in 1999 (115) investigated the biomechanics of the un-affected limb movement during gait, the results showed that abnormal temporal which occurred in the un-affected side may be related to the diminished propulsive power and, hence, leading to the reductions in swing phase

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duration on the un-affected side. In addition, it may be caused by an adaptive mechanism that is used to secure dynamic balance and body support by prolonging the time spent with both legs on the ground.

2.4.4.3 Kinetics

Kinetic is the study of the forces and their derivatives that bring movement occurred. An understanding of kinetic of gait is essential to appropriate interpretation of human locomotion. In clinical gait analysis, moment of forces that muscle generates about joint centers is assuming to be the cause of movements of joints and hence of body segments (139). Kinetic information is particularly satisfy and useful in understanding and interpreting the characteristics of pathological such as hemiplegic gait (26, 28, 36).

2.4.4.3.1 Ground reaction forces (GRFs)

The GRFs as measured by force platform reflect the net vertical and two shear forces acting between foot and the force platform. These three forces are an algebraic summation of the mass-acceleration products of all body segments when the foot is in contact with the ground. Interpretation of these waveforms cannot interpret individuals segment doing during movement. Each force gives the information of how acceleration in each plane occurred. Clinically, GRF provides how different from normal walking data (140). However, the GRF is regarded as a representative measurement of gait, because it is the external force involved in walking and it affects the acceleration of the body's COM. The goal of locomotion is to drive the COM stable in the desired direction. Therefore, GRF is may be used as an appropriate global parameter to characterize gait also (97).

The vertical force component is required to counteract the gravity and equal to body weight. Vertical force used for maintaining level of body's COM above the ground. Whenever the total vertical reaction force is less than the force of body weight, COM of body is accelerating downward. However, a vertical GRF which greater than the body weight indicates an acceleration upward. Similarly, shear forces correlate with progression and lateral accelerating of body. These forces

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are necessary to initiate and bring the body move forward as well as to alter the speed and direction of walking. When a constant speed is obtained, shear forces have no longer be required to maintain the speed of walking. However, bipedal locomotion which body support by one leg and then to the other, requires shear force to maintain body balance. Maintaining of the postural balance in the line of progression requires braking shear force at the early stance phase of gait. As the body pass over the supporting foot, AP shear force drops to zero. Then, when the foot going to leaves the ground, body requires propulsive shear force to generate body move forward (141).

There have been many studies of the GRF during walking in hemiplegic subjects (37, 111, 142). Many differences showed between patients with stroke and able-bodied subjects. Hemiplegic subjects have a larger vertical component of the GRF at foot strike than do normal subjects and lack of the peak vertical force associated with push off. Even though the shape of the force curve was consistent for each subject, there was significant variability in the shear and the vertical force components across the steps. The abnormality of GRF is consistent with kinematic deficits. It appears that subjects with hemiplegia have the difficulty to control force parameter, especially during weight acceptance and in the period of transferring the weight to the contralateral limb.

The antero-posterior ground reaction force (AP-GRF) may represent an appropriate parameter of measuring the contribution of the affected leg to the coordinated task of forward propulsion during walking. Previous studies have implemented the AP-GRF as a measure of the forward propulsion and braking in people with hemiparesis using a cane for ambulatory assistance (142). Bowden et al in 2006 (111) studied the relationship of GRF, gait speed, and the severity in 47 chronic stroke patients. The results showed that A-P GRF measures were correlated with both gait speed and hemiparetic severity. These measures were also strongly correlated with positive work and net work values obtained during the pedaling task. The percentage of total propulsion generated by the affected leg was calculated and found to be 16%, 36%, and 49% for those with high, moderate, and low hemiparetic severity, respectively.

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Kim and Eng in 2003 (37) determined effect of symmetry of temporo-spatial and vertical GRF to gait speed. The results demonstrated that among variables tested, symmetry index of vertical GRF was the highest related to gait speed. This significant correlation provides some support for interventions aimed at improving weight bearing through the affected limb to establish symmetry and ultimately increase function.

2.4.4.3.2 Net joint moment and power

Stroke patients demonstrate the alterations of magnitude and values from those of normal. Deviated patterns interpret that strategies used in patient was differ from normal and eventually presented with the compensatory movement (143). A large variation patterns exist among patients with stroke and corresponding to the individuals. Kim et al in 2004 (26) identified 3D kinematic and kinetic gait profiles in 20 individuals with chronic stroke. It was found that more than one type of kinematic and kinetic pattern was identified in all three planes of movement. Kinetic data was demonstrated as a large flexor moment of hip, large extensor moment of knee. In the frontal plane, the deviation showed a prolonged hip abduction pattern during swing period in the stroke subjects. Moreover, stroke subjects who were in the fast speed group did not exhibit the gait patterns closed to those of the normal healthy. For example, in the frontal plane, a variation from the typical pattern such a hip abductor pattern during the swing was more common among the fast group. It is suggested that the prolonged hip abductor pattern may be a mechanism to compensate for the lack of dorsiflexion and the insufficient flexion at the hip and knee required to clear the ground.

Kerrigan et al in 2001 (133) studied the kinetic profiles of hip, knee, and ankle in spastic stiff legged gait in hemiplegic patients. The results showed that for all joint kinetic parameters, the standard deviations were greater in the subjects with hemiparesis in comparison with those of normal. The significant differences were found in many kinetics variables. Both peak knee power absorption and ankle power generation were decreased significantly in the subjects with hemiparesis. There were also increases in peak external-hip flexion torque in stance,

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hip-power generation in loading response, knee-extension torque in midstance, ankle-dorsiflexion torque, and ankle-power absorption in stance. There was substantial variability in most torque and power values among subjects, which was significantly greater than that observed in the control subjects.

Numerous kinematic and kinetic gait patterns were identified across subjects indicating that persons with stroke use the different strategies to achieve the goal of walking (27, 28, 114). The results of the previous studies indicated that the means of therapeutic procedures should be individualized depending upon the type of disturbed motor control presented by the individual person.

2.5 Factors Influencing Gait Characteristics

Many factors are considered to affect the gait characteristics. It includes gender, age, movement speed, and fitness.

2.5.1 Gender

Gender based-differences in walking characteristics have been performed for many years ago. It was summarized that females walk with shorter step length, narrower step width, smaller joint range of motions, but walking with greater cadence than males (144). For the gender-based differences of kinematic variables, Kerrigan et al in 2000 (145) found no significant differences between gender in the quality or magnitude of the sagittal and coronal knee torque during the early and midstance phases. However, the limitation of the study is related to the reliability of coronal knee angular motion.

A study comparing 99 males and females of similar ages reported statistically difference in joint kinematics, but these differences expressed only 2-4 degrees and the significant difference is negligible in clinic. This study also reported that females exhibit a statistically greater extension moment of the knee at the initial contact and a greater flexion moment in the preswing with the increasing in power absorption or generation of the hip, knee, and ankle joints. The author suggested that

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these differences in kinetic measures might assist in an explaining of the higher incidence of knee osteoarthritis in women (146).

Cho et al in 2004 (147) determined the effect of gender to gait variables in Korean adults, it was found that female showed slower gait speed than male. However, when normalize the gait speed to the leg length, no gender differences were found. In general, the three dimensional gait analysis data were similar between males and females. Wider pelvis in female influenced to the motions of hip, knee, and ankle on the coronal plane. Females walked with more pelvic tilted anteriorly and more up-down oblique motion. Hip displacement showed more flexion, adduction, and internal rotation. In addition, knee displacement showed more valgus. It was suggested that these may related to the difference of the anatomical structure and skeletal dimension (147).

2.5.2 Age

Age appears to affect gait, as exhibits by the development of gait from infant to older adults. The gradual adaptation of stable bipedal ambulation is a normal part in human development. Functional changes accompany with the normal aging process in the sensory, neurological, and musculoskeletal systems (148, 149). These changes ultimately express as the changes in biomechanics of gait performance (150). Dynamic walking balance is achieved by integrating sensory inputs from the visual, vestibular, and propioceptive systems (151). Gait adaptation as seen in the elderly populations may be associated with the general decreases in muscle strength due to loss of motor neurons, muscle fibers, and aerobic capacity (152).

Age-related changes in the parameters of gait have been extensively documented (85, 152-154). These studies have reported that there was reductions in self-selected gait speed, stride length, and lower extremity joint range of motion in older adults (15, 155, 156) . Increased double-support time and increased gait variability were also documented in the elderly populations (155, 156). Grabiner et al in 2001(157) studied the effect of age on the temporo-spatial gait variables. The most consistent finding of this study is that the healthy older participants walked with

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significantly larger step width than younger participants. When gait speed was controlled, it was found that no differences in the stride parameters between young and the elderly groups.

In the kinematic variables alterations with the age effect, there was reported that the pelvic motions in the sagittal, frontal, and transverse planes were systematically reduced with age. Moreover, trunk motion also showed reduced flexion–extension and increased rotation in the elderly group (157). Kerrigan et al in 1998 (154) studied the biomechanical changes in 31 elderly compared with the healthy young subjects during gait. Several kinematic and kinetic differences between young and elderly adults were found but did not persist when gait speed was increased. Biomechanical differences persisted at both comfortable and fast gait speeds were reduced peak hip extension, increased anterior pelvic tilt, and reduced ankle plantarflexion and ankle power generation.

The study of kinetic changes in gait in aging showed significantly lower plantar-flexor power in terminal stance phase of gait and simultaneous reduction in knee absorption power for the elderly subjects (156). The ankle plantarflexor power assists in forward progression of the body. Moreover, it supported the body from collapse with a combination of knee extensors and hip extensors during double support period (158). It is reported that ankle plantarflexors and knee extensors generation capacity decreases with age. These impairments of power generation capacity may limit gait speed and step length in the elderly (159). Therefore, the elderly represents a potential impairment limit (159, 160).

Both Kerrigan et al in 1998 (154) and DeVita and Hortobagi in 2000 (159) found the increasing hip extensors moment in the elderly. Neuromuscular adaptations of the hip to compensate the reduction capacity of ankle plantarflexors possibly provide for trunk stability with increased hip extensors moment. Thus, hip flexion contracture with aging may present as an additional limiting impairment, particularly in a combination with the weakness of the ankle plantarflexors.

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2.5.3 Gait speed

As normal people increase gait speed, their gait cycle time, single limb support, and double limb support decrease whereas the stride length and cadence increase but the temporo-spatial symmetry between limbs unchanged. The findings of Murray et al in 1984 (161), showed that at faster gait speed, most of the limb segments move through a greater range of motion in a shorter period of time than at slower gait speed. For instance, the motions of head and knee flexion during heel strike were increased when gait speed increased. Head motion was greatly move during fast gait speed as a result of the limbs being more outstretched as the longer step length was made. The latter, knee has more flexion to act as a shock absorbing mechanism for the more forceful onset during walking at fast speed. Two main roles of the muscles in the regulation of walking speed is to control the accelerating and decelerating forces of individual's body segments to establish safe forward progression. As a result, the amplitude of the muscle activity increases with gait speed because of the need for larger muscular force output (61). These requirements of fast gait speed are undoubtedly increase the EMG activity. As well as the study in hip kinematic and kinetic by Crowinshield et al in 1987 (162), kinematic and kinetic parameters have a significant dependency on the subject walking speed. Hip flexion-extension, stride length, hip resultant force and moment were all increasing with increasing gait speed.

Many studies supported that ankle plantarflexors power played an important role in propelling the body in the late stance (63, 137, 163). Ankle plantarflexors power provides the propulsive force in the early stance. The GRF is directed backward in the early stance and reverse to forward before the toe-off. Therefore, the stance limb must be delayed forward motion at the initial contact and propelling the body forward before toe-off.

From the net joint moment curve represented in many literatures, ankle moment was responsible for support throughout the stance period (63, 97, 158, 164). In the late stance, the ankle plantarflexors moment required for supporting and generating a propulsive contribution that was always significant and relatively more at the slow gait speed. Rehabilitation in pathological cases who usually walking with

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slow gait speed and loss of ankle support function and alters propulsion function by using compensation of other joints. In healthy young subjects, adaptation to change speed requirements occurred primarily in the activation of hip flexors and extensors. Thus, maintaining or rehabilitating ambulatory function requires maintenance of adequate hip strength and range of motion, and the ability to modulate the activation of muscles acting about the hip (165).

Stroke subject can increase their overground gait speed two to three times beyond the comfortable levels under proper instruction and safe environment. Such increase is attributable to larger step lengths and shorter cycle durations on the affected and un-affected sides, regardless of the functioning levels (42). Muscle strength, ankle push off during the stance phase (156) and hip flexion pull off in the early swing (28, 38) are known as major determinants of gait speed after stroke. Slow walking after stroke may be the behavioral adaptation to poor endurance, poor balance, and poor stability. Other common factors such as altered perception of self motion and cognitive or attention deficit may also play an important role.

Fast walking may improve kinematics and muscle activation pattern of hemiparetic gait. Pathological gait is known to be associated with a high energy demand compared with the normal gait. The greater efficiency may be attributable to longer time to control the lower limbs, co-ordination, of intra-limb and inter-limb movements (42).

2.5.4 Fitness

"Physical activity" describes all bodily movement that is produced by the contraction of skeletal muscle and which substantially increases energy expenditure. This includes the muscular work required in maintaining posture, walking, performing all activities of daily living. Any temporary and involuntary reduction in the ability of muscle to generate force and/or sustain repeated contractions both during and after physical activity is termed "fatigue". "Physical fitness" is a set of attributes, which people have or achieve, that relate to the ability to perform physical

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activity. The key components of physical fitness include the cardio-respiratory fitness, muscular strength, and body composition (166).

Several studies (166-169) have shown that the subjects with chronic hemiparetic stroke have profoundly diminished cardiovascular fitness, muscular atrophy in the affected extremity, and altered body composition that are related to gait deficit severity. Gait deficits are associated with abnormal gait biomechanics, spasticity and reduced oxidative capacity of the affected limb musculature, with subsequent increased energy requirements for expenditure during walking (108). In addition, functional disability after hemiparetic stroke may be compounded by physical deconditioning and muscular wasting, factors related to disuse and advancing age (169). The decrease in gait speed also reported with age appears to depend on an individual fitness and other factors besides of age itself. Coexisting joint impairments, decreased strength of lower extremity muscles, restricted joint mobility, impaired motor control, sensory disturbances, impaired muscle tone, and pain are also explain as the factors involved in diminished gait speed (124, 170).

Alterations in fitness may influence the restoration and maintenance of walking ability and, ultimately, have an impact on long-term disability. In patients with stroke, although muscle weakness and loss of co-ordination are the primary impairments that affect gait after a stroke, impaired cardio-respiratory fitness may secondarily affect gait performance by limiting walking endurance (168). Therefore, improvement in gait in the elderly required consideration of the contribution factor of dysfunction by discriminating the causes of dysfunction (96).

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CHAPTER III
MATERIALS AND METHODS

3.1 Subjects

Each of thirty control and the stroke subjects were participated in the present study (Appendix L). The age and gender of subjects in the control group were matched with those of the stroke group. The inclusion and exclusion criteria of the stroke group were as follows;

- Inclusion criteria for the stroke group

- First stroke caused by cerebrovascular disease, not from brain tumor and trauma
- Independent walking distance of at least 10 meters without assistive devices
- Can perform active movement of the lower extremity joint

- Exclusion criteria for the stroke group

- Subarachnoidal stroke
- Musculoskeletal or cardiopulmonary complication that interferes with walking ability
- Other neurological problems such as Parkinsonism or Alzheimer disease
- Having major perceptual disturbance such as unilateral neglect
- Having the problems of cognitive status and communication deficits

- Criteria for the control group

- No history of neuromuscular impairment
- No significant deficit of vision and hearing
- No problems causing abnormal gait

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3.2 Instrumentation

1. Vicon^{TM} Motion Analysis System (Oxford Metrics Ltd., Oxford, UK) consists of
   - Six video cameras
   - Vicon^{TM} data station 612
   - Workstation PC with Windows XP version
   - Polygon software
2. Calibration L-frame and calibration wand
3. One force platform (AMTI-Advanced Mechanical Technology, Inc, Series: OR6-7-4000, 464 × 508 × 82.5 mm: Watertown, Massachusetts, USA)
4. AMTI Amplifier (MSA-6: Watertown, Massachusetts, USA)
5. Thirty-four 1.0-cm-diameter reflective spherical markers
6. Vernier caliper (Lafayette Instrument Company), Model 01291, Lafayette, Indiana, USA)
7. Automatic blood pressure monitor machine (OMRON), T5-M: 3X00348A, Japan)
8. Double-side adhesive tape and hypoallergenic tape
9. Measuring tape
10. Hammer

3.3 Error of measurement

To ensure the accuracy of motion data from Vicon^{TM} Motion Analysis System, error of the measurement was determined before the data collecting process (Appendix J).

3.4 Calibration of Vicon^{TM} Motion System

Prior to each data collection, system calibration was performed to allow software calculating the relative location and orientation of all cameras. There were two steps of Vicon^{TM} Motion System calibration, static and dynamic calibration.

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3.4.1 Static calibration

Static calibration calculated the origin or center of the capture volume and determined the orientation of the three dimensional workspace.

3.4.2 Dynamic calibration

This process was necessary to ensure that all cameras were able to view the area used for capture. Calibration wand was used to allow all cameras view in mutiple orientation. Every camera was calibrated with mean residual factor less than 2.00 mm over the volume of $1.0 \times 2.0 \times 2.5$ m.

3.5 Procedure

This study was approved by the Ethical Committee, Faculty of Medicine Siriraj Hospital, Mahidol University (Appendix A). All testings were performed in the Motion Laboratory, Faculty of Physical Therapy and Applied Movement Science, Mahidol University. The researcher informed subjects about the purpose, procedure, and advantage of the study prior to participation in the study (Appendix B.1). Subjects were asked to sign an informed consent if they agree to participate in the study (Appendix B.2). Stroke subjects were screened for their cognitive status with the Thai Mental State Examination (TMSE) (171) (Appendix D). Stroke subjects were excluded when their TMSE were lower than 23.

3.5.1 Physical examination

Blood pressure and heart rate were measured by an automatic blood pressure monitor equipment (OMRON, T5-M). After that, researcher recorded demographic data and assessed passive range of motion (PROM), proprioceptive and exteroceptive sensations, leg length (Appendix C), muscle tone of lower extremity muscles using Modified Ashworth Scale (MAS) (Appendix E), lower extremity motor function using Fugl-Meyer Assessment (FMA) (Appendix F), and postural balance using Berg Balance Scale (BBS) (Appendix G). Then, subjects were prepared for the laboratory data collecting process.

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3.5.2 Subjects preparation

Subjects were asked to wear a sleeveless shirt and short pants to measure their anthropometric data and attach the markers on their body before gait data collection.

3.5.2.1 Anthropometric data measurement

The anthropometric data were necessary in the Plug-In-Gait models for calculating in the kinematic and kinetic models. Anthropometric data including height, body weight, leg length, hand thickness, and joint width of elbow, knee, and ankle were measured before marker placement.

Height of the subject was assessed in centimeter and body weight was assessed in kilogram. Other anthropometric measurements including leg length, hand thickness, and joint width were assessed in supine position. Leg length was assessed with measuring tape from anterior superior iliac spine to ipsilateral medial malleolus in centimeter. Hand thickness and joints' width were assessed with Vernia caliper (Anthropometer, Lafayette, Indiana, USA) in centimeter. Hand thickness was measured between the dorsum and palmar surfaces of the hand. Elbow width was measured between medial and lateral epicondyles of humerus during elbow flexion. Knee width was assessed between medial and lateral condyles of femur. Ankle width is the medio-lateral distance across the malleoli.

3.5.2.2 Marker placement

Thirty-four reflective spherical markers were attached on subjects' bony prominences as shown in Table 3.1. Marker numbers 1-18 were placed on the upper part of the body and 19-34 were placed on the lower part of the body. The total body segments were simulated and presented on the screen of the monitor as illustrated in Figure 3.1.

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Table 3.1 Marker placement

Marker positions	
1. Left front head	18. Right 2nd metacarpal
2. Right front head	19. Left ASIS
3. Left back head	20. Right ASIS
4. Right back head	21. Left PSIS
5. 7th Cervical spinous process	22. Right PSIS
6. 10th Thoracic spinous process	23. Left thigh wand marker
7. Jugular notch	24. Right thigh wand marker
8. Xiphoid process	25. Left lateral condyle of femur
9. Left acromion process	26. Right lateral condyle of femur
10. Right acromion process	27. Left tibial wand marker
11. Left lateral epicondyle of humerus	28. Right tibial wand marker
12. Right lateral epicondyle of humerus	29. Left lateral malleolus
13. Left wrist marker A (radial side)	30. Right lateral malleolus
14. Left wrist marker B (ulna side)	31. Left heel
15. Right wrist marker A (radial side)	32. Right heel
16. Right wrist marker B (radial side)	33. Left 2nd metatarsal
17. Left 2nd metacarpal	34. Right 2nd metatarsal

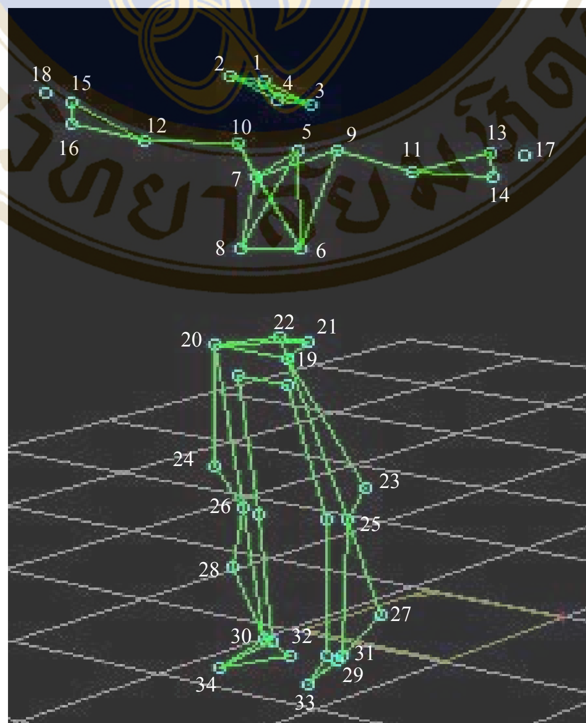

Figure 3.1 Simulation of total body segment and marker positions.

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3.5.5 Data collection

3.5.5.1 Subject calibration

All subjects were asked to stand in the comfortable erect position with arm straight by their side for static calibration. Data were collected for three seconds by six video cameras of Vicon™ Motion System.

3.5.5.2 Walking data collection

The familiarization of walking with set up was needed prior to the data collection. Subjects walked barefoot along the 8-m walkway, with starting point approximately 3 meters outside the calibration volume. Walking data were collected for two speeds; comfortable speed and self selected fast speeds. First, subjects were asked to walk through the capture volume at their own comfortable speeds. After comfortable speed walking, 10 minutes rest was allowed. Then, subjects were asked to walk at self-selected fast speed. Three successful walking trials were collected for each walking speed. All walking data were recorded by six video cameras at 100 frames/second and kinetic data were collected at a rate of 1000 Hz. Motion and force data were synchronously be recorded using one force platform embedded in the walkway. Starting position was adjusted until foot placement occurred exclusively on the force platform for one stance phase without targeting. One physical therapist walked beside the subjects with stroke to prevent falling or any hazardous situation.

3.5.5.3 Data acquisition, processing, and analysis

Data acquisition started from linking analogues and images data by Vicon™ Datastation. Then, the markers were identified and calculated for coordination of x, y, and z for each marker from calibration coefficients of each camera using Vicon Workstation. Three dimensional coordinates of the markers were reconstructed with direct linear transformation method to obtain 3D picture.

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For data processing, firstly, the desired range of gait motion picture was expressed completely kinematic and kinetic forms. Secondly, cleaning and linking marker trajectory were performed by the Workstation software. Thirdly, filter the marker trajectory was done by the Woltring method which based on generalized cross validated spline technique. Fourthly, calculating process was based on Plug-In-Gait model which used the Euler method to calculate the relative segmental motion. Joint angles was calculated which based on segmental motion of the distal segment on the fixed point of the proximal segment. Finally, Polygon software was used to report and obtain the data.

For data analysis, gait events were determined according to the criteria of Rancho Los Amigos. Temporo-spatial data was calculated according to gait event setting which were determined by foot markers trajectory in antero-posterior direction. Test-retest reliability of gait event marking was presented with acceptable criteria (Appendix H). Gait event in the angular displacement analyses were investigated at initial contact, midstance, and toe off. Initial contact and toe off events were determined from heel and toe markers trajectory along the antero-posterior direction. Furthermore, midstance event was determined according to the position of peak total body center of mass displacement in vertical axis during stance period. In addition, gait speed was calculated from the average data of total body center of mass velocity in antero-posterior direction. For the kinetic data, ground reaction forces were normalized with individual body weight and were reported with percentage of body weight. Lastly, all gait data were expressed as average values from three trials of walking. The average data were selected only on the middle path of walkway to eliminate the effect of acceleration and deceleration. Summarization of the procedure is illustrated in Figure 3.2.

3.5.5.4 Data deduction

The results of biomechanic variables were obtained from the averaged data of three walking trials which were analyzed only on one gait cycle exhibiting at the middle part of walkway. Because left and right legs were not

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influenced to the gait biomehanics, the data of the control came from an averaged data of six walking files of the left and right sides (Appendix I). In the stroke, the affected and unaffected data came from three averaged data of each side separately.

Gait speed both in the comfortable and fast speeds were calculated from the averaged data of total body center of mass velocity in the antero-posterior direction.

This pilot study presented the number of subjects who express data in the different direction as represented with the positive and negative signs. Numbers of subjects were reported in the variables of symmetrical index variables, angular displacement, angular velocity, and ground reaction forces.

3.5.5.5 Data reporting

- **Clinical measurements**

Clinical measures included the TMSE, the MAS of five lower extremity muscle group (hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors), the FMA for the lower extremity, and the BBS for the affected and the un-affected sides were reported in scores.

- **Laboratory measurements**

Temporo-spatial data

Cadence was reported in steps per minute. Double support time, stride time, single support time, and step time were reported in second. Step width and step length were reported in meter. Gait speed was reported in meter per second.

Kinematics

Patterns of the angular displacement of the hip, knee, and ankle were illustrated in the graphs, the X-axis represents the consumed time of walking (% gait cycle) and the Y-axis represents the angle (degrees). In the sagittal plane, the positive value represents the flexion of hip and knee joints and

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dorsiflexion of ankle joint. The negative value represents the extension of hip and knee joints and plantarflexion of ankle joint. In the frontal plane, the positive value represents the abduction of hip, knee, and ankle joints. The negative value represents the adduction of the hip, knee, and ankle joints. In the transverse plane, the positive value represents the internal rotation of the hip, knee, and ankle joints. The negative value represents the external rotation of the hip, knee, and ankle joints.

Patterns of the angular velocity of the hip, knee, and ankle in the sagittal plane were illustrated in the graphs, the X-axis presents the consumed time of walking (% gait cycle) and the Y-axis presents the velocity (degrees/s). In the sagittal plane, the positive value represents the velocities of the hip and knee flexion and ankle dorsiflexion. The negative value represents the velocities of the hip extension, knee extension and ankle plantarflexion.

Ground reaction forces (GRFs)

GRFs were normalized by the individual body weight and then reported in percentage of body weight. Pattern of GRFs in three axes (X, Y, and Z) were illustrated in the graphs, positive and negative signs represent the direction of GRFs in each axis. In the X-axis, positive and negative signs represent the medial and lateral forces, respectively. In the Y-axis, positive and negative signs represent the propulsive and braking forces, respectively. In the Z-axis, positive sign represents the vertical force.

3.6 Statistical Analysis

The Kolmogorov Smirnov Goodness of Fit test assessed the distribution of the data. The statistical significance was set at $p<0.05$.

1. Pearson’s correlation coefficient examined the associations between Fugl-Meyer and gait speed, Fugl-Meyer and gait symmetry, BBS scores and gait speed, and BBS scores and gait symmetry.
2. Spearman rank correlation coefficient examined the associations between MAS scores and gait speed and MAS scores and gait symmetry.

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3. Unpaired t-test assessed the difference in all gait assessments between the control and the stroke groups.

4. Paired t-test assessed the difference in all gait assessments between affected and unaffected sides.

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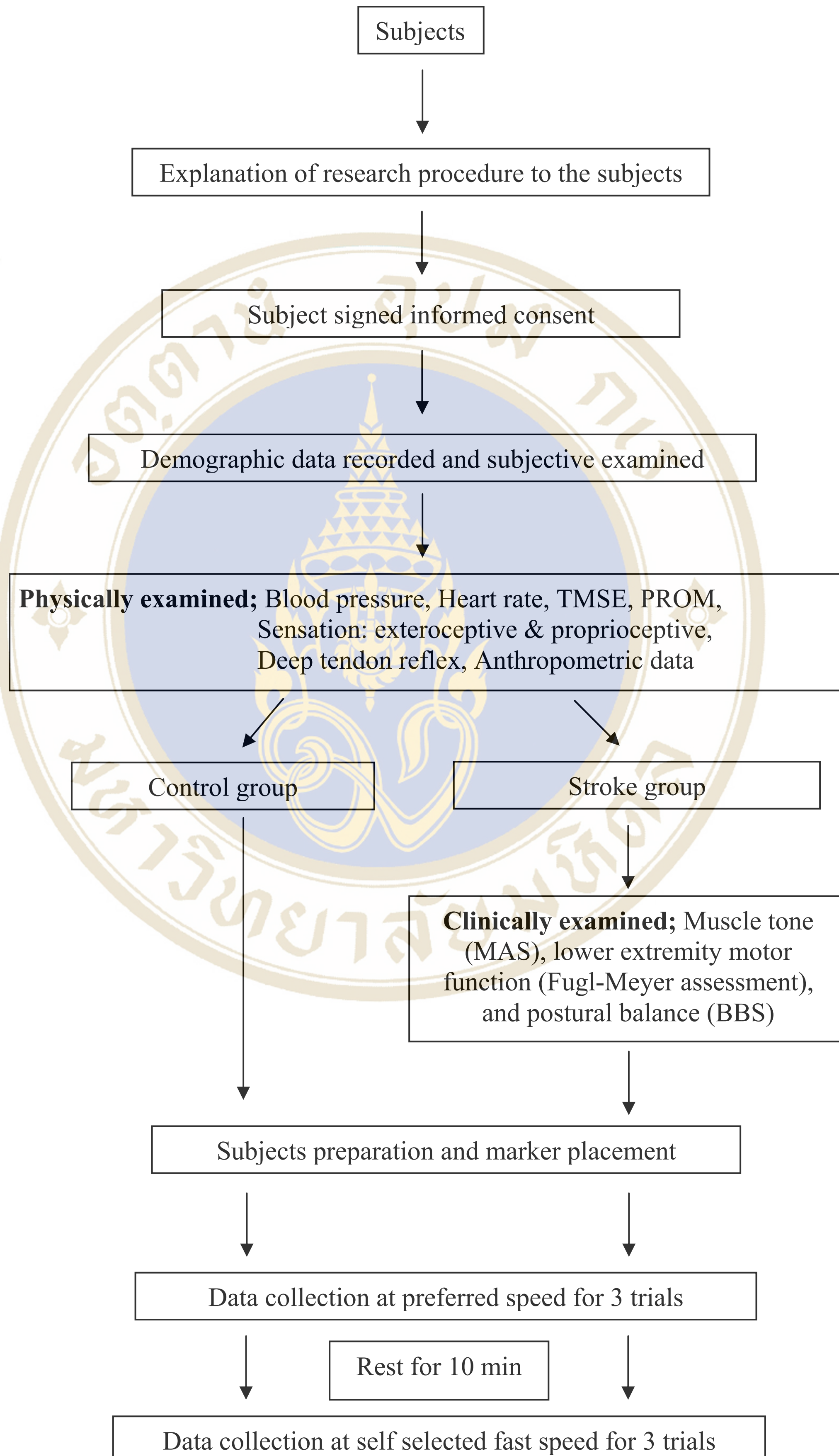

Figure 3.2 Procedure of the present study.

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CHAPTER IV
RESULTS

4.1 Subject Characteristics

Thirty subjects in each of the control and the stroke groups participated in this study. There were twenty-five male and five female subjects in each group. Both groups had similar age, body weight, and height (p>0.05) as presented in Table 4.1.

In the stroke group, twelve subjects were hemorrhagic stroke and the eighteen were ischemic stroke. Eight subjects had right sided and twenty-two subjects had left sided hemiparesis. Average time since stroke was 32.30±19.63 months, ranged from 3-72 months. All participants were able to communicate and follow the instructions.

Table 4.1 Comparisons of age, body weight, and height of the stroke (n=30) and the control (n=30)

Characteristics	Stroke (Mean±SD)	Control (Mean±SD)	p-value[a]
Age (yr)	53.30±8.77	52.97±8.82	0.88
Body weight (kg)	68.05±13.96	64.58±10.55	0.28
Height (cm)	166.03±7.40	165.62±6.39	0.82

Note: a = p-value from Unpaired t-test

Clinical examinations for the stroke were composed of Thai Mental State Examination (TMSE), Modified Ashworth Scale (MAS) of five lower extremity muscle groups i.e. hip adductors (HA), hip extensors (HE), knee extensors (KE), ankle plantarflexors (AP), and ankle invertors (AI), Fugl-Meyer Motor Assessment (FMA) of lower extremity, Berg Balance Scale (BBS) which was classified into the scores of

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the affected and un-affected sides. In addition, comfortable and fast gait speeds were recorded. The results of these clinical measures are shown in Table 4.2.

The TMSE score of all stroke subjects exhibited in the acceptable range which was higher than 23. Mean and standard deviation of TMSE were 27.93±1.84, ranged from 24 to 30. The MAS scores of the lower extremity muscle groups were ranged from 0 to 2 for the hip adductor, hip extensor, and knee extensor muscles. Large range of scores (0 to 3) were found in the ankle plantarflexor and invertor muscles. The FMA scores of the stroke were in the moderate to high degree (24.33±5.18, ranged from 16 to 33) from the full score of 34. The BBS scores which were classified into the score of the affected and un-affected sides expressed the higher score in the un-affected side. Mean and standard deviation of BBS of the un-affected side data were 51.67±3.26, ranged from 45 to 56, whereas the mean and standard deviation of the affected side were 49.47±3.69, ranged from 40 to 55.

For comfortable and fast gait speeds, stroke group showed slower gait speed than the controls (1.15±0.15 m/s for the comfortable gait speed and 1.58±0.18 m/s for the fast gait speed). Means and standard deviations of the comfortable and fast gait speeds in the stroke were 0.64±0.21 and 0.86±0.33 m/s respectively. Comfortable gait speed ranged from 0.29 to 1.27 m/s and fast gait speed ranged form 0.35 to 1.61 m/s.

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Table 4.2 Clinical measures in the stroke (n=30)

No	TMSE (score)	MAS (score)					FMA (score)	BBS (score)		Gait speed (m/s)	
		HA	HE	KE	AP	AI		A	U	COM	FAST
1	29	0	1	0	1+	1	30	52	55	0.74	1.01
2	26	1	0	0	1+	1+	20	48	49	0.32	0.42
3	26	0	0	1	1	1	20	45	45	0.66	0.80
4	30	1	1	1+	1+	1+	20	48	52	0.72	0.93
5	29	1	1+	0	2	1+	16	48	51	0.39	0.54
6	30	0	0	0	0	1	21	47	51	0.62	1.05
7	28	1+	1+	1+	2	1+	19	44	47	0.65	1.17
8	29	0	0	0	0	0	33	55	55	0.94	1.47
9	25	1+	1+	1+	1+	1+	21	51	52	0.55	0.70
10	27	0	0	0	0	0	33	53	54	0.62	0.78
11	30	0	0	0	1	1	28	51	53	0.79	1.09
12	29	0	0	0	1	1	30	54	56	0.79	0.96
13	29	1	1	1	1	1	24	54	56	0.85	1.20
14	26	0	0	0	1	1	28	46	47	0.68	0.93
15	26	1	0	0	1+	1+	33	53	53	0.83	1.39
16	28	1	1	0	1+	1+	29	54	56	0.89	1.36
17	29	1+	1+	1+	2	2	18	48	51	0.65	0.72
18	30	0	0	0	0	0	33	51	52	1.27	1.61
19	27	1	1	1	1+	1+	22	40	46	0.58	0.63
20	24	1	1	1	1+	1+	22	50	52	0.41	0.47
21	30	1+	2	1+	2	2	20	47	48	0.36	0.45
22	30	1	1	1	1	1	29	51	53	0.53	0.68
23	29	1	1	1	1+	1+	25	54	56	0.79	1.00
24	28	0	1	0	1+	1+	25	50	52	0.46	0.53
25	25	1+	1+	1+	1+	1+	27	44	51	0.46	0.57
26	28	2	2	2	3	3	20	54	56	0.41	0.49
27	29	1	1+	1+	1+	2	21	46	47	0.70	0.90
28	27	1+	1+	2	2	2	20	47	48	0.29	0.35
29	30	1+	1+	1+	1+	1+	25	50	53	0.65	0.94
30	25	1	1	1	1+	1+	18	49	53	0.51	0.66
Means	27.93	-	-	-	-	-	24.33	49.47	51.67	0.64	0.86
SD	1.84	-	-	-	-	-	5.18	3.69	3.26	0.21	0.33
Min	24	0	0	0	0	0	16	40	45	0.29	0.35
Max	30	2	2	2	3	3	33	55	56	1.27	1.61

Note: TMSE = Thai Mental State Examination Scores
MAS = Modified Ashworth Scores
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
FMA = Fugl-Meyer Motor Assessment (lower extremity)
BBS = Berg Balance scores
A = Affected side
U = Un-affected side
COM = Comfortable gait speed
FAST = Fast gait speed

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4.2. Correlations between Clinical Measures and Gait Performances

4.2.1 Correlations between clinical measures and gait speeds

In the present study, clinical measures included muscle tone of five lower extremity muscle groups which was assessed by the MAS. Lower extremity motor assessment was assessed by the FMA of the lower extremity, and functional balance was assessed by the BBS. The distribution of BBS score, FMA score, comfortable and fast gait speeds were normal distribution in the stroke group. The relationships between MAS score and two gait speeds were tested by Spearman rank correlation statistic. Moreover, relationships between the BBS and FMA scores and both gait speeds were conducted by Pearson's product moment correlation statistic.

Table 4.3 shows the correlations between clinical measures and two gait speeds, the comfortable and fast gait speeds of thirty stroke subjects. The results showed significant relationships except for the association between gait speeds and the BBS score of the un-affected side. The associations between gait speeds and MAS score demonstrated a negative relationship, whereas the relationship between gait speeds and BBS and between FMA demonstrated a positive relationship. Among three clinical measures, highest relationship between clinical measures and gait speeds were exhibited in the FMA score at the comfortable gait speed (r_p = 0.631).

4.2.2 Correlations between clinical measures and gait symmetries

Symmetrical gait variable was detected with the symmetrical indexes (SI). Six symmetrical gait variables contained the first (Z1) and the second (Z2) peak vertical ground reaction forces in percentage of body weight (%BW), single support time (SST) in second (s), step time in second (s), stance time in percentage of gait cycle (%GC), and swing time in percentage of gait cycle (%GC) at the comfortable and fast gait speeds. Percentage of symmetrical index of each variable was calculated by the following equation (50);

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$$SI = \frac{(V_{affected} - V_{un\text{-}affected}) \times 100\%}{1/2\,(V_{affected} + V_{un\text{-}affected})}$$

Symmetrical gait variables expressed both the positive and negative values depending on the predominant function of the value of the affected or un-affected side. The positive sign represented that the value of the affected side was greater than that of the un-affected side. The negative sign indicated that the values of the affected side were less than that of the un-affected side.

Table 4.4 presents raw data and percentage of the stroke subjects showing the symmetrical gait variables at the comfortable and fast gait speeds. It was found that all subjects with stroke showed the consistency pattern in the variables of stance and swing times which were reported in all negative and positive values, respectively. Inconsistency pattern was found in the Z1, Z2, SST, and step time. Most subjects with stroke demonstrated the pattern in the positive values for the variables of Z1 and step time. In addition, the negative values were found in those of the variables of Z2 and SST.

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Table 4.3 Correlations between the Modified Ashworth Scale (MAS) of hip adductors (HA), hip extensors (HE), knee extensors (KE), ankle plantarflexors (AP), and ankle invertors (AI), the Berg Balance Scale (BBS) for the affected (A) and the un-affected (U) sides, the Fugl-Meyer Motor Assessment for lower extremity (FMA) and the comfortable (COM) and the fast gait speeds in the stroke (n=30)

Clinical measures		**Speeds**	**Correlation coefficient**	***p*-value**
MAS	HA	COM	r_s = -0.471	0.009*
		FAST	r_s = -0.427	0.019*
	HE	COM	r_s = -0.490	0.006*
		FAST	r_s = -0.469	0.009*
	KE	COM	r_s = -0.387	0.035*
		FAST	r_s = -0.411	0.024*
	AP	COM	r_s = -0.536	0.002*
		FAST	r_s = -0.529	0.003*
	AI	COM	r_s = -0.528	0.003*
		FAST	r_s = -0.569	0.001*
BBS	A	COM	r_p = 0.398	0.029*
		FAST	r_p = 0.400	0.029*
	U	COM	r_p = 0.347	0.060
		FAST	r_p = 0.339	0.067
FMA		COM	r_p = 0.631	0.001*
		FAST	r_p = 0.610	0.001*

Note: *= Significant difference at *p*-value<0.05
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic

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Table 4.4 Raw data and percentage of the symmetrical index of the first peak vertical force (Z1), the second peak vertical force (Z2), and the single support time (SST), step time, stance time, and swing time at the comfortable (COM) and fast (FAST) gait speeds in the stroke (n=30)

No	Z1		Z2		SST		Step time		Stance time		Swing time	
	COM	FAST	COM	FAST	COM	FAST	COM	FAST	COM	FAST	COM	FAST
1	5.27	7.43	-3.45	-4.64	-19.03	-10.52	22.22	18.50	-3.53	-7.62	6.35	12.73
2	6.26	18.03	1.83	-6.90	-47.12	-44.12	43.09	51.66	-21.11	-27.76	46.14	56.36
3	2.98	-3.86	-10.12	-7.39	-46.15	-45.61	40.80	37.06	-25.41	-16.97	42.72	26.64
4	12.93	11.45	-0.20	-8.75	-31.21	-35.29	41.61	38.87	-12.39	-21.95	24.85	38.14
5	-0.78	9.01	-2.60	-4.83	-31.13	-30.27	-5.18	8.00	-8.98	-13.95	27.98	32.94
6	3.37	-5.63	-0.37	0.80	-29.94	-11.50	17.16	23.16	-11.79	-16.56	25.22	29.20
7	6.69	0.16	-9.57	-15.60	-31.44	-21.74	20.14	24.36	-11.06	-10.34	23.64	17.51
8	0.99	15.68	1.97	3.25	-10.33	-6.71	2.22	0.71	-1.55	-2.76	2.83	4.21
9	-3.10	2.19	1.60	-0.46	-37.02	-40.69	27.92	21.91	-14.22	-20.94	28.61	43.19
10	3.52	-11.67	5.95	1.32	-3.36	-4.59	-1.76	-4.72	-3.81	-2.46	7.55	4.31
11	5.97	25.79	-3.25	5.02	-13.66	-5.50	21.59	12.23	-6.57	-9.26	13.33	15.28
12	1.35	2.89	1.07	2.11	-4.00	-11.56	8.79	7.45	-6.77	-5.67	12.56	9.85
13	-4.78	-5.92	-6.78	-13.89	-32.26	-24.41	27.39	13.29	-17.61	-8.85	34.55	15.25
14	-2.49	3.94	-1.41	7.53	-19.42	-18.04	17.69	15.25	-8.10	-12.12	16.20	20.15
15	6.92	-11.52	-0.68	-12.33	-15.72	-15.11	5.93	10.28	-6.00	-1.87	11.70	3.11
16	-4.50	-6.15	1.71	4.65	-6.69	-9.09	3.79	3.44	-2.58	-2.22	4.44	3.33
17	11.19	11.77	-0.49	-1.07	-30.28	-25.64	25.44	20.83	-13.60	-15.65	28.45	30.86
18	-3.35	-17.54	-2.85	-8.87	1.29	0.45	1.24	3.20	-0.11	-4.60	0.18	6.74
19	-3.51	-2.00	3.66	-1.08	-6.48	-18.11	4.46	6.76	-4.13	-4.69	8.71	9.44
20	3.38	3.50	0.74	-2.78	-31.13	-25.79	9.98	19.82	-8.82	-17.03	24.73	40.27
21	9.14	14.45	3.48	3.57	-24.96	-21.63	23.63	17.25	-12.28	-9.71	29.05	20.60
22	13.79	9.24	-4.62	-15.81	-24.75	-16.45	25.30	27.47	-9.38	-8.36	19.80	16.07
23	-1.08	-14.63	-3.36	-7.07	6.84	9.09	-8.65	-13.42	-3.79	-9.14	7.05	16.64
24	10.17	10.46	-3.70	-9.90	-58.82	-56.54	41.52	45.70	-23.88	-27.02	55.19	54.24
25	8.00	2.79	3.41	-0.07	-22.13	-21.17	51.11	49.22	-13.43	-17.24	32.84	36.39
26	16.17	1.99	2.09	2.73	-41.82	-32.09	49.87	49.19	-13.67	-18.31	32.60	44.43
27	11.15	-2.32	-0.39	-5.49	-27.99	-28.33	26.80	30.53	-14.98	-19.15	30.69	33.87
28	1.99	3.14	6.37	6.71	25.48	31.66	21.21	12.42	-10.10	-9.04	30.17	24.92
29	8.24	5.64	-1.02	-2.00	-27.50	-23.32	18.37	21.05	-8.20	-12.47	16.69	22.58
30	4.77	11.18	-10.62	-15.17	-46.95	-48.52	53.85	53.16	-20.48	-30.92	43.28	53.29
+ (%)	22 (73)	20 (67)	12 (40)	10 (33)	3 (10)	3 (10)	27 (90)	28 (93)	0 (0)	0 (0)	30 (100)	30 (100)
- (%)	8 (27)	10 (33)	18 (60)	20 (67)	27 (90)	27 (90)	3 (10)	2 (7)	30 (100)	30 (100)	0 (0)	0 (0)

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The degree of relationship between clinical measures and symmetrical gait variables was determined in the group of subjects who had the same pattern. The absolute values of symmetrical index variables were used to investigate the relationship with the clinical measures.

Table 4.5 presents the correlations between the MAS of hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors, the BBS for the affected and the un-affected sides, the FMA for lower extremity and the Z1 and the Z2 at the comfortable and fast gait speeds in the stroke. Data from twenty-two stroke subjects were determined the relationship between the Z1 and MAS, BBS, and FMA at the comfortable gait speed, and twenty data were determined that relationship at the fast gait speed. Significant correlations were found in all MAS scores of five lower extremity muscle groups at the comfortable gait speed. The degree of relationships were in moderate level for the hip adductors (r_s = 0.532), hip extensors (r_s = 0.585), knee extensors (r_s = 0.465), ankle plantarflexors (r_s = 0.498), and ankle invertors (r_s = 0.554). However, no correlation was found between the Z1 and MAS of all muscle groups. There was no correlation either between the Z1 and BBS or the Z1 and FMA at both gait speeds. For the Z2, eighteen data were determined the relationship of Z2 and all clinical measures at the comfortable gait speed, and twenty data were determined for that relationship at the fast gait speed. Only the MAS score of the hip extensors at the fast gait speed showed significant relationship with the Z2 (r_s = -0.449).

Table 4.6 presents the correlations between the MAS of hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors, the BBS for the affected and the un-affected sides, the FMA for lower extremity and the SST and step time at the comfortable and fast gait speeds in the stroke. Twenty seven data from the stroke was determined the relationships between the SST and all clinical measures for the comfortable and fast gait speeds. At the comfortable gait speed, significant correlations in the SST were found with MAS score of the ankle invertors (r_s = 0.394) and FMA (r_p = -0.662). At the fast gait speed, the significant correlations were found

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with MAS score of the hip extensors (r_s = 0.391), knee extensors (r_s = 0.457), ankle plantarflexors (r_s = 0.480), ankle invertors (r_s = 0.548), but not with MAS score of the hip abductors (r_s = 0.369). Additionally, the significant correlation was found in FMA (r_p = -0.648).

Twenty seven and twenty eight data from stroke subjects were determined the relationships between step time and the Modified Ashworth Scale (MAS) of hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors, the BBS for the affected and the un-affected sides, the FMA for lower extremity at the comfortable and fast gait speeds, respectively. Significant correlations were found between the step time and MAS score of hip extensors (r_s = 0.391), knee extensors (r_s = 0.454), and ankle invertors (r_s = 0.389) at the comfortable gait speed. Only MAS score of knee extensors at the fast gait speed was significantly correlated (r_s = 0.425) to the step time. In addition, there was significant relationship between step time and FMA at both the comfortable and fast gait speeds (r_p = -0.556 and r_p = -0.447).

The relationships between all clinical measures and stance time as well as swing time were determined in all stroke subjects (n=30) as shown in Table 4.7. There were significant relationships between the stance time and the MAS score of knee extensors at the comfortable and fast gait speeds (r_s = 0.451 and r_s = 0.397), ankle invertors at the comfortable and fast gait speeds (r_s = 0.426 and r_s = 0.451), and FMA at the comfortable and fast gait speeds (r_p = -0.620 and r_p = -0.656).

For the swing time, mild to moderate degree relationships were found in the MAS scores of all five lower extremity muscle groups in both the comfortable and fast gait speeds (r_s = 0.362 to 0.531). Significant relationships were also found in the FMA at both the comfortable and fast speeds (r_p = -0.676 and r_p = -0.682).

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Table 4.5 Correlations between the Modified Ashworth Scale (MAS) of hip adductors (HA), hip extensors (HE), knee extensors (KE), ankle plantarflexors (AP), and ankle invertors (AI), the Berg Balance Scale (BBS) for the affected (A) and the un-affected (U) sides, the Fugl-Meyer Motor Assessment for lower extremity (FMA) and the first peak vertical force (Z1) and the second peak vertical force (Z2) at the comfortable (COM) and fast (FAST) gait speeds in the stroke (n=30)

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
The first peak vertical force	MAS	HA	COM	r_s = 0.532*	22	The second peak vertical force	MAS	HA	COM	r_s = -0.089	18
			FAST	r_s = -0.425	20				FAST	r_s = -0.375	20
		HE	COM	r_s = 0.585*	22			HE	COM	r_s = -0.038	18
			FAST	r_s = -0.426	20				FAST	r_s = -0.449*	20
		KE	COM	r_s = 0.465*	22			KE	COM	r_s = -0.050	18
			FAST	r_s = -0.440	20				FAST	r_s = -0.313	20
		AP	COM	r_s = 0.498*	22			AP	COM	r_s = -0.051	18
			FAST	r_s = -0.291	20				FAST	r_s = -0.331	20
		AI	COM	r_s = 0.554*	22			AI	COM	r_s = -0.297	18
			FAST	r_s = -0.196	20				FAST	r_s = -0.399	20
	BBS	A	COM	r_p = -0.075	22		BBS	A	COM	r_p = -0.148	18
			FAST	r_p = 0.166	20				FAST	r_p = 0.294	20
		U	COM	r_p = 0.036	22			U	COM	r_p = -0.148	18
			FAST	r_p = 0.068	20				FAST	r_p = 0.173	20
	FMA		COM	r_p = -0.273	22		FMA		COM	r_p = -0.260	18
			FAST	r_p = 0.107	20				FAST	r_p = 0.145	20

Note: *= Significant difference at *p*-value<0.05
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic

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Table 4.6 Correlations between the Modified Ashworth Scale (MAS) of hip adductors (HA), hip extensors (HE), knee extensors (KE), ankle plantarflexors (AP), and ankle invertors (AI), the Berg Balance Scale (BBS) for the affected (A) and the un-affected (U) sides, the Fugl-Meyer Motor Assessment for lower extremity (FMA) and single support time and step time at the comfortable (COM) and fast (FAST) gait speeds in the stroke (n=30)

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
Single support time	MAS	HA	COM	$r_s = 0.308$	27	Step time	MAS	HA	COM	$r_s = 0.344$	27
			FAST	$r_s = 0.369$	27				FAST	$r_s = 0.298$	28
		HE	COM	$r_s = 0.309$	27			HE	COM	$r_s = 0.391$*	27
			FAST	$r_s = 0.391$*	27				FAST	$r_s = 0.278$	28
		KE	COM	$r_s = 0.369$	27			KE	COM	$r_s = 0.454$*	27
			FAST	$r_s = 0.457$*	27				FAST	$r_s = 0.425$*	28
		AP	COM	$r_s = 0.378$	27			AP	COM	$r_s = 0.357$	27
			FAST	$r_s = 0.480$*	27				FAST	$r_s = 0.257$	28
		AI	COM	$r_s = 0.394$*	27			AI	COM	$r_s = 0.389$*	27
			FAST	$r_s = 0.548$*	27				FAST	$r_s = 0.354$	28
	BBS	A	COM	$r_p = -0.184$	27		BBS	A	COM	$r_p = -0.198$	27
			FAST	$r_p = -0.259$	27				FAST	$r_p = -0.237$	28
		U	COM	$r_p = -0.233$	27			U	COM	$r_p = -0.088$	27
			FAST	$r_p = -0.302$	27				FAST	$r_p = -0.132$	28
	FMA		COM	$r_p = -0.662$*	27		FMA		COM	$r_p = -0.556$*	27
			FAST	$r_p = -0.648$*	27				FAST	$r_p = -0.447$*	28

Note: *= Significant difference at p-value<0.05
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic

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Table 4.7 Correlations between the Modified Ashworth Scale (MAS) of hip adductors (HA), hip extensors (HE), knee extensors (KE), ankle plantarflexors (AP), and ankle invertors (AI), the Berg Balance Scale (BBS) for the affected (A) and the un-affected (U) sides, the Fugl-Meyer Motor Assessment for lower extremity (FMA) and stance time and swing time at the comfortable (COM) and fast (FAST) gait speeds in the stroke (n=30)

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
Stance time	MAS	HA	COM	$r_s = 0.331$	30	Swing time	MAS	HA	COM	$r_s = 0.362$*	30
			FAST	$r_s = 0.284$	30				FAST	$r_s = 0.367$*	30
		HE	COM	$r_s = 0.335$	30			HE	COM	$r_s = 0.377$*	30
			FAST	$r_s = 0.340$	30				FAST	$r_s = 0.420$*	30
		KE	COM	$r_s = 0.451$*	30			KE	COM	$r_s = 0.433$*	30
			FAST	$r_s = 0.397$*	30				FAST	$r_s = 0.430$*	30
		AP	COM	$r_s = 0.302$	30			AP	COM	$r_s = 0.366$*	30
			FAST	$r_s = 0.341$	30				FAST	$r_s = 0.440$*	30
		AI	COM	$r_s = 0.426$*	30			AI	COM	$r_s = 0.475$*	30
			FAST	$r_s = 0.451$*	30				FAST	$r_p = 0.531$*	30
	BBS	A	COM	$r_p = -0.316$	30		BBS	A	COM	$r_p = -0.336$	30
			FAST	$r_p = -0.298$	30				FAST	$r_p = -0.269$	30
		U	COM	$r_p = -0.352$	30			U	COM	$r_p = -0.344$	30
			FAST	$r_p = -0.232$	30				FAST	$r_p = -0.204$	30
	FMA		COM	$r_p = -0.620$*	30		FMA		COM	$r_p = -0.676$*	30
			FAST	$r_p = -0.656$*	30				FAST	$r_p = -0.682$*	30

Note: *= Significant difference at p-value<0.05
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic

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4.3 Comparisons of Gait Biomechanic Characteristics between the Stroke and the Control

Prior to the comparison, the data distribution was investigated by Kolmogorov Smirnov Goodness of Fit test, and all variables showed normal distribution.

4.3.1 Temporo-spatial

Temporo-spatial data in the present study were divided into two sections. The first comparison was the data analysis between the control and the stroke. It was composed of cadence (steps/min), double support time (s), step width (m), stride length (m), stride time (s), and gait speed (m/s). There were significant differences in all variables between the control and the stroke for both the comfortable and fast gait speeds, as shown in Table 4.8. Cadence, stride length, and gait speed both in the comfortable and fast speeds of the stroke were significantly less than those of the control. In addition, double support time, step width, and stride time of the stroke significantly showed greater values than those of the control.

The second comparison: SST (s), step length (m), and step time (s) were analyzed between the control and the affected side of the stroke, between the control and the un-affected of the stroke, and between the affected and the un-affected sides of the stroke, as shown in Table 4.9. There were significant differences in all variables at both the comfortable and fast gait speeds between the control and the un-affected side in the stroke, and between the un-affected and the affected sides in the stroke. Between the control and the affected side in the stroke, significant differences were shown in the step length and the step time at both the comfortable and the fast gait speeds.

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Table 4.8 Comparisons of cadence (steps/min), double support time (s), step width (m), stride length (m) and time (s), and gait speed (m/s) between the stroke (n=30) and the control (n=30) in the comfortable (COM) and fast (FAST) gait speeds

Variables	Speeds	Stroke (Mean±SD)	Control (Mean±SD)	*p*-values[a]
Cadence (steps/min)	COM	85.86±12.92	109.10±8.79	0.001*
	FAST	101.23±16.74	128.49±7.22	0.001*
Double support time (s)	COM	0.53±0.18	0.29±0.05	0.001*
	FAST	0.39±0.16	0.20±0.03	0.001*
Step width (m)	COM	0.24±005	0.17±0.02	0.001*
	FAST	0.24±0.06	0.17±0.03	0.001*
Stride length (m)	COM	0.88±0.18	1.25±0.11	0.001*
	FAST	1.01±0.23	1.48±0.14	0.001*
Stride time (s)	COM	1.44±0.24	1.11±0.09	0.001*
	FAST	1.23±0.22	0.94±0.05	0.001*
Gait speed (m/s)	COM	0.64±0.21	1.15±0.15	0.001*
	FAST	0.86±0.33	1.58±0.18	0.001*

Note: *= Significant difference at *p*-value<0.05
a= *p*-value from Unpaired t-test

Table 4.9 Comparisons of single support time (SST) (s), step length (m), and step time (s) between the control and the un-affected of the stroke, the control and the affected of the stroke, and the un-affected and the affected sides of the stroke (n=30) in the comfortable (COM) and fast (FAST) gait speeds

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
SST (s)	COM	0.41±0.03	0.51±0.08	0.40±0.05	0.001*	0.510	0.001*
	FAST	0.37±0.02	0.45±0.07	0.37±0.05	0.001*	0.973	0.001*
Step length (m)	COM	0.63±0.05	0.43±0.11	0.47±0.08	0.001*	0.001*	0.013*
	FAST	0.74±0.07	0.49±0.14	0.53±0.11	0.001*	0.001*	0.013*
Step time (s)	COM	0.55±0.04	0.64±0.12	0.79±0.15	0.001*	0.001*	0.001*
	FAST	0.47±0.03	0.55±0.10	0.68±0.15	0.001*	0.001*	0.001*

Note: * = Significant difference at *p*-value<0.05
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides

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4.3.2 Kinematics

4.3.2.1 Angular displacement (degrees)

Patterns of the angular displacements of the hip, knee, and ankle joints in the sagittal, frontal, and transverse planes of the control, the affected side, and the un-affected side of the stroke at the comfortable and fast gait speeds were illustrated in the Figures 4.1-4.9. In the stroke, the deviated patterns were presented away from the control in both the affected and un-affected sides and more abnormal patterns were found in the affected than the un-affected side in all joints.

Figures 4.1-4.3 show the hip angular displacements in the sagittal, frontal, and transverse planes of the control, the affected side, and the un-affected side of the stroke in both the comfortable and fast gait speeds. Less degree of the hip movements in all three planes were demonstrated in the affected side than in the un-affected side. The patterns showing in the affected and the un-affected sides of the stroke were decreased in range of motion than the control especially in the frontal and transverse planes.

Figures 4.4-4.6 show the knee angular displacements in the sagittal, frontal, and transverse planes of the control, the affected side, and the un-affected sides of stroke in both the comfortable and fast gait speeds. Predominantly, abnormal pattern of the knee was observed more often in the affected side than in the un-affected side. Sagittal knee patterns of the affected and the un-affected sides of the stroke showed similar to those of the control as exhibited with the double knee flexion curve, but the affected side of the stroke expressed the pattern with hyperextension of the knee at approximately 40% gait cycle. The period from the first to the second knee flexion was prolonged in the affected and the un-affected sides of the stroke.

Figures 4.7-4.9 show the ankle angular displacements in the sagittal, frontal, and transverse planes of control, the affected side, and the un-affected side of stroke both in the comfortable and fast gait speeds. Less ankle motions were demonstrated in all three planes of movement in both the affected side and the un-affected side of the stroke compare to the control. In the sagittal plane, the stroke

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showed lack of ankle plantarflexion in both the affected and the un-affected sides. In addition, less range of movement were demonstrated in the affected lower limbs, especially in both the frontal and transverse planes.

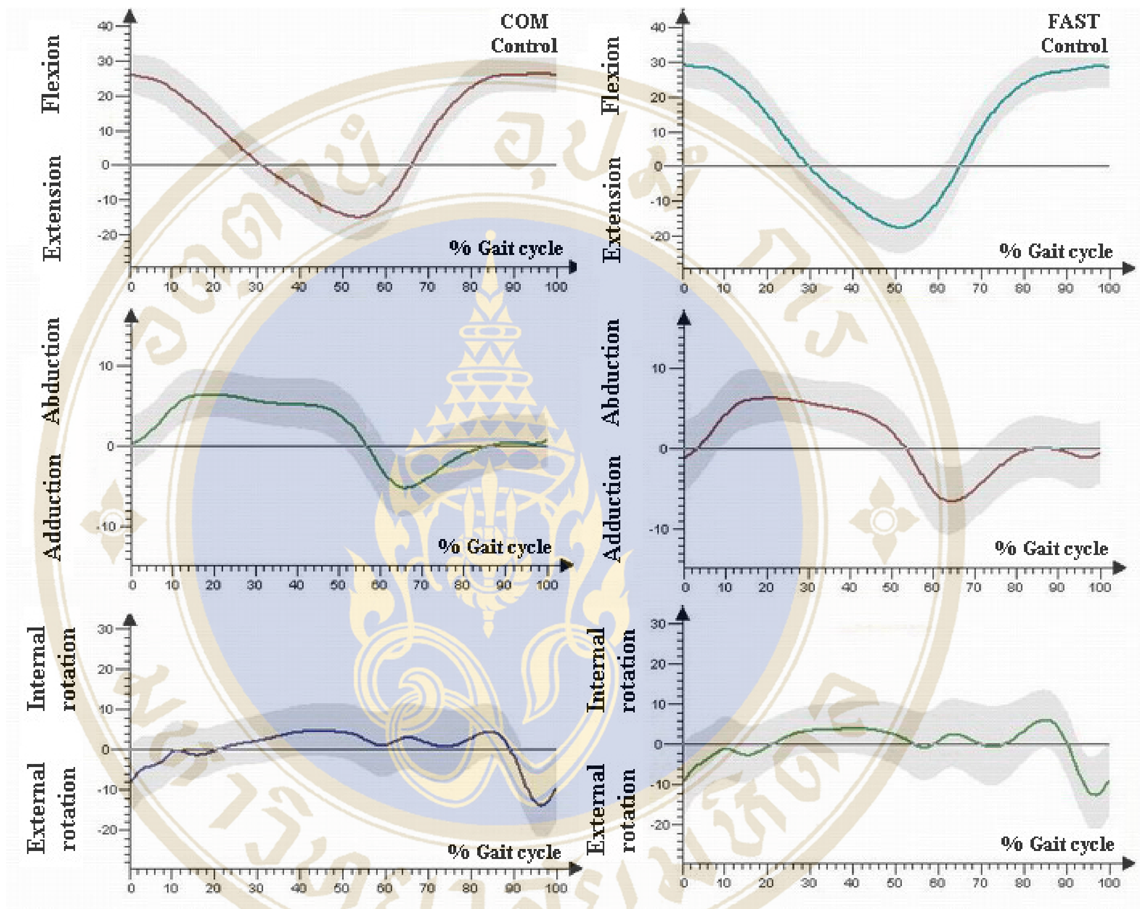

Figure 4.1 Hip angular displacements (degrees) in the sagittal, frontal, and transverse planes of the control at comfortable (COM) and fast (FAST) gait speeds.

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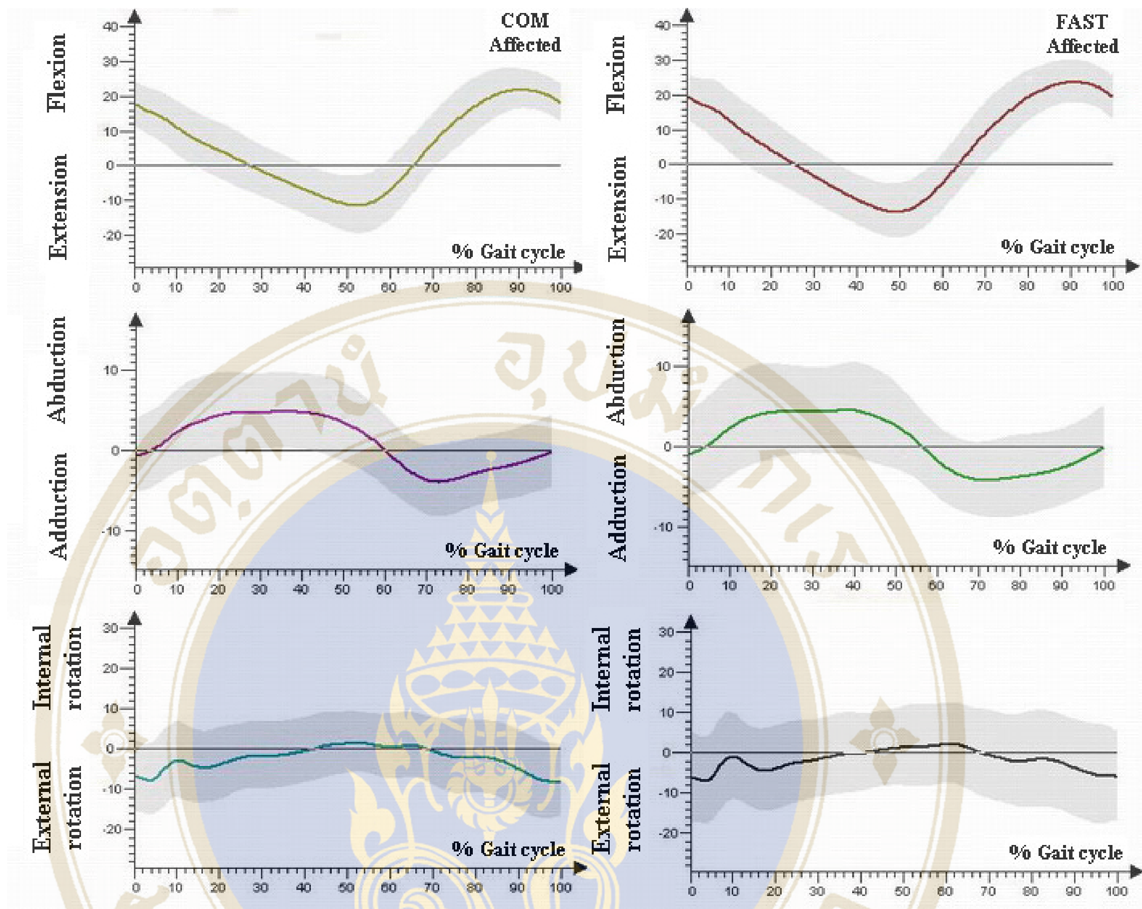

Figure 4.2 Hip angular displacements (degrees) in the sagittal, frontal, and transverse planes of the affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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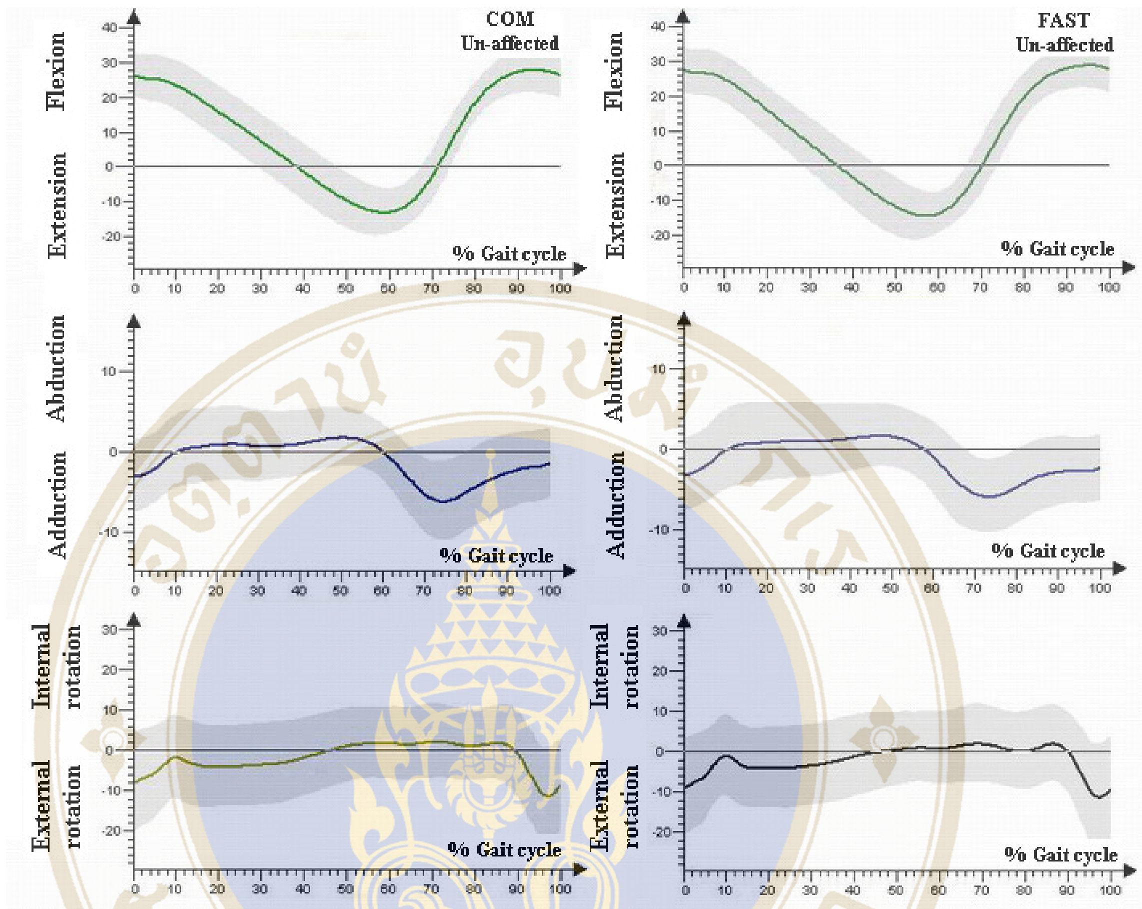

Figure 4.3 Hip angular displacements (degrees) in the sagittal, frontal, and transverse planes of the un-affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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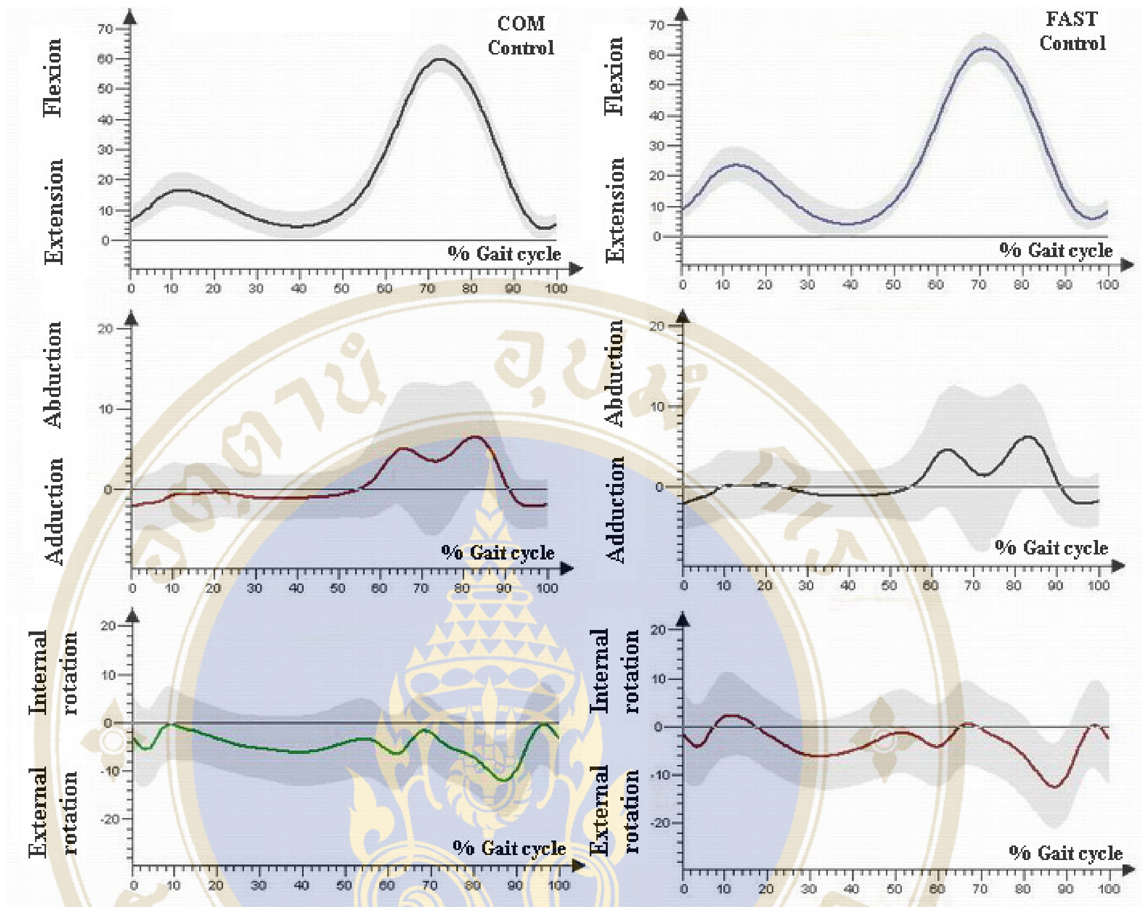

Figure 4.4 Knee angular displacements (degrees) in the sagittal, frontal, and transverse planes of the control at comfortable (COM) and fast (FAST) gait speeds.

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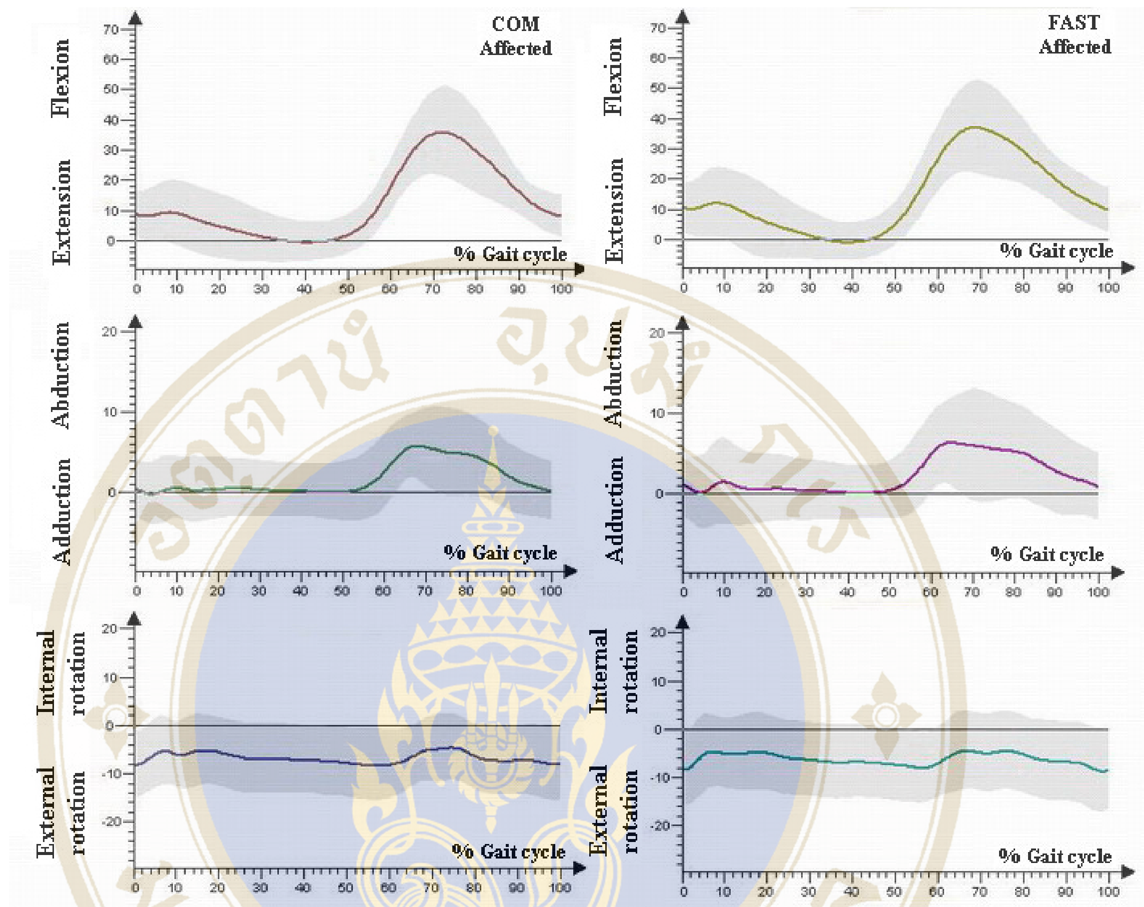

Figure 4.5 Knee angular displacements (degrees) in the sagittal, frontal, and transverse planes of the affected side the stroke at comfortable (COM) and fast (FAST) gait speeds.

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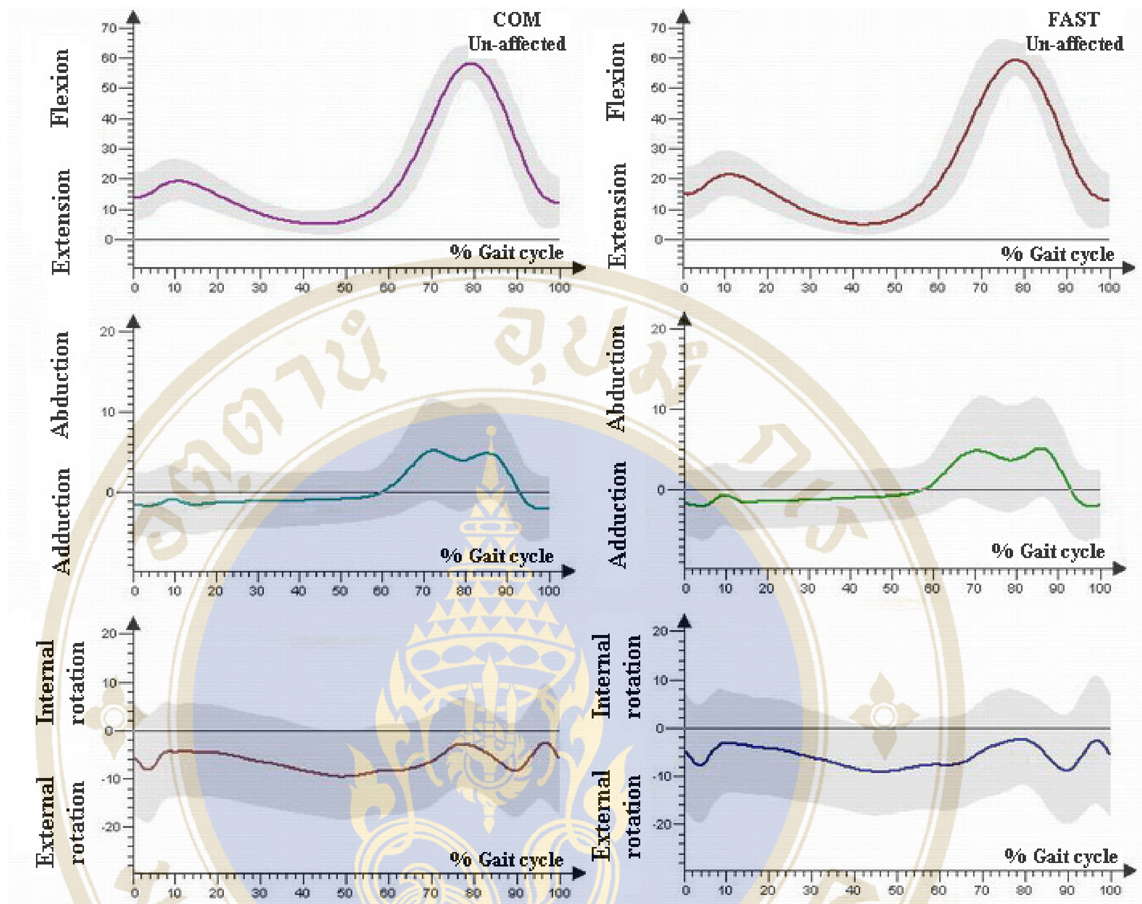

Figure 4.6 Knee angular displacements (degrees) in the sagittal, frontal, and transverse planes of the un-affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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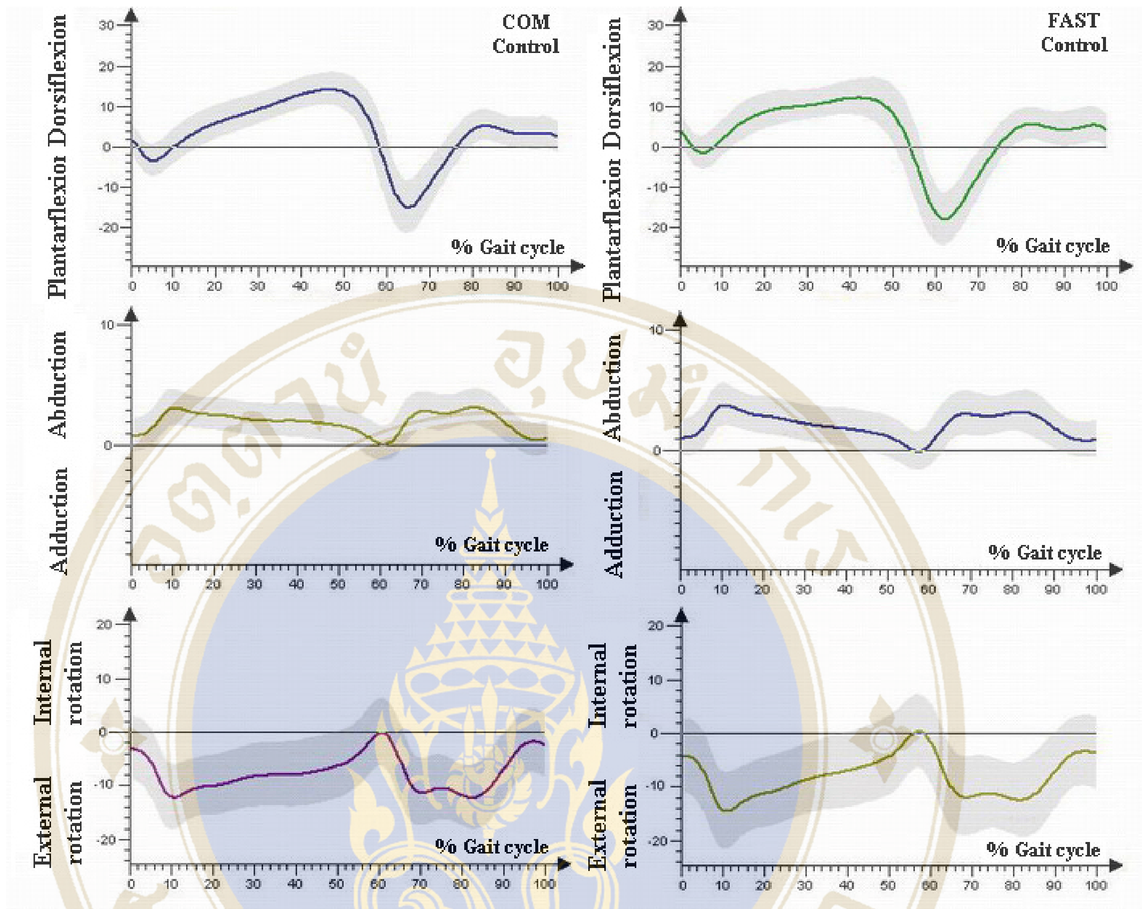

Figure 4.7 Ankle angular displacements (degrees) in the sagittal, frontal, and transverse planes of the control at comfortable (COM) and fast (FAST) gait speeds.

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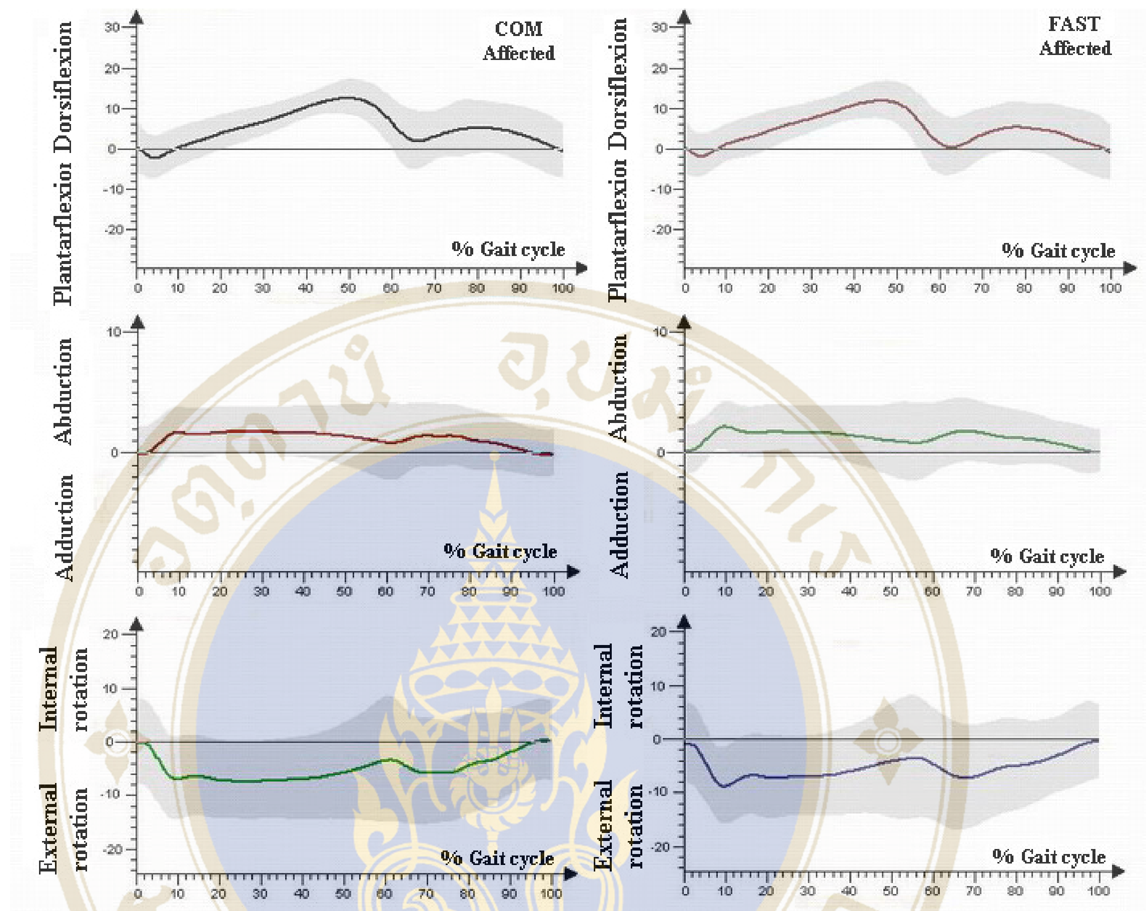

Figure 4.8 Ankle angular displacements (degrees) in the sagittal, frontal, and transverse planes of the affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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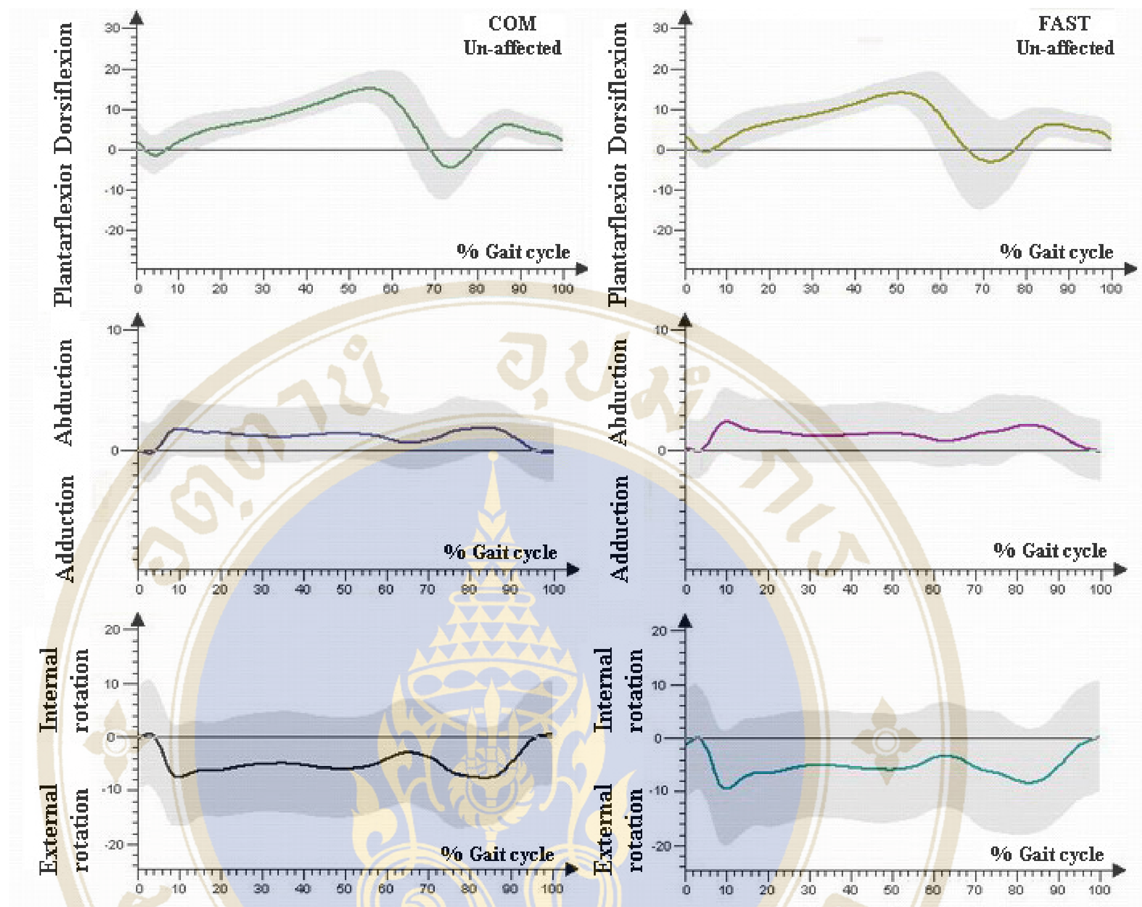

Figure 4.9 Ankle angular displacements (degrees) in the sagittal, frontal, and transverse planes of the un-affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

Number of subjects showing different trends of the angular displacement of the hip, knee, and ankle in the sagittal, frontal, and transverse planes during initial contact (IC), midstance (MS), and toe off (TO) events at the comfortable and fast gait speeds are presented in Tables 4.10 and 4.11, respectively. The results demonstrated the inconsistent pattern in the frontal and transverse planes more than the sagittal plane. Furthermore, the inconsistent pattern was seen more often in the stroke compared to the control. The positive and negative signs represent the direction of action corresponding to the plane of movement. Prior to comparing the angular displacements of the hip, knee, and ankle between the control and the un-affected side of the stroke, between the control and the affected side of the stroke, and between the un-affected and the affected sides of the stroke, the data of each group were come

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from the averaged values of three walking trials. In the stroke, data were divided into the affected and the unaffected sides of the stroke. In addition, the average of the left and the right sides data were used for the control group.

Table 4.12 shows the comparisons of angular displacements in the sagittal, frontal, and transverse planes of the hip, knee, and ankle between the control and the un-affected side of the stroke, the control and the affected side of the stroke, and the un-affected and the affected sides of the stroke in the comfortable gait speed at the IC, MS, and TO.

In the sagittal plane, there were significant differences in the angular displacement between the control and the un-affected side of the stroke in the hip, knee, and ankle joints at the TO and in the knee at the IC. When comparing between the control and the affected side of the stroke, there were significant differences in the angular displacement in the hip at the IC and in the knee and the ankle at the MS and TO. Between the un-affected and affected sides of the stroke, there were significant differences in the angular displacement in the knee at all three events, in the hip at the IC and MS, and in the ankle at the MS and TO.

In the frontal plane, there were significant differences in the angular displacements between the control and the un-affected side of the stroke in the hip at the IC and the MS and in the ankle at the MS. Between the control and the affected side of the stroke, there were significant differences in the angular displacements in the hip at the TO and in the knee at the IC. Between the un-affected and the affected sides of the stroke, there were significant differences of the angular displacements in the hip at the MS and the TO and in the knee at the IC and the MS.

In the transverse plane, there was significant difference in the angular displacements between the control and the unaffected side of the stroke in the hip at the MS. Between the control and the affected side of the stroke, there were significant differences in the angular displacements in the hip at the MS and in knee at

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the IC. Between the un-affected and the affected sides of the stroke, there was no significant difference in the angular displacements in any joints.

Table 4.13 shows the comparisons of angular displacements in the sagittal, frontal, and transverse planes of the hip, knee, and ankle between the control and the un-affected side of the stroke, the control and the affected of the stroke, and the un-affected and the affected sides of the stroke in the fast gait speed at the IC, MS, and TO.

In the sagittal plane, there were significant differences in the angular displacement between the control and the un-affected side of the stroke in the hip, knee, and ankle at the TO and in the knee at the IC. Between the control and the affected side of the stroke, there were significant differences in the angular displacement in the hip at the IC and the TO, in the knee at the MS and the TO, and in the ankle at all three events. Between the un-affected and the affected sides of the stroke, there were significant differences in the angular displacement in the hip and the ankle at the IC, in the hip, knee, and ankle at the MS, and in the knee and the ankle at the TO.

In the frontal plane, there were significant differences in the angular displacements between the control and the un-affected side of the stroke in the hip at the IC and MS and in the ankle at the MS. Between the control and the affected side of the stroke, there were significant differences in the angular displacements in the hip at the TO and in the knee at the IC. Between the un-affected and the affected sides of the stroke, there were significant differences in the angular displacements in the hip at the TO and in the knee at the IC and MS.

In the transverse plane, there were significant differences in the angular displacements between the control and the unaffected side of the stroke in the hip and the ankle at the MS. Between the control and the affected side of the stroke, there were significant differences in the angular displacements in the hip at the MS

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and in the knee at the IC. Between the un-affected and the affected sides of the stroke, there was no significant difference of the angular displacements in any joints.

Table 4.10 Number of subjects for the control (C), the un-affected side of the stroke (U), and the affected side of the stroke (A) showing angular displacement of hip, knee, and ankle joints in the sagittal (F = flexion, E = extension, DF = dorsiflexion, PF = plantarflexion), frontal (AB = abduction, AD = adduction), and transverse (IR = internal rotation, ER = external rotation) planes at the comfortable gait speed at the initial contact (IC), midstance (MS), and toe off (TO)

Plane	Joint	Action	IC Number of subject			MS Number of subject			TO Number of subject		
			C	U	A	C	U	A	C	U	A
Sagittal	Hip	F (+)	30	30	30	24	25	22	8	12	9
		E (-)	0	0	0	6	5	8	22	18	21
	Knee	F (+)	29	30	27	30	29	20	30	30	30
		E (-)	1	0	3	0	1	10	0	0	0
	Ankle	DF (+)	22	23	16	30	30	26	0	2	19
		PF (-)	8	7	14	0	0	4	30	28	11
Frontal	Hip	AB (+)	16	8	16	30	19	27	3	1	8
		AD (-)	14	22	14	0	11	3	27	29	22
	Knee	AB (+)	8	11	18	11	13	18	24	24	28
		AD (-)	22	19	12	19	17	12	6	6	2
	Ankle	AB (+)	25	15	19	30	24	26	17	21	20
		AD (-)	5	15	11	0	6	4	13	9	10
Transverse	Hip	IR (+)	2	6	5	21	12	13	22	19	18
		ER (-)	28	24	25	9	18	17	8	11	12
	Knee	IR (+)	7	8	2	4	7	7	3	7	4
		ER (-)	23	22	28	26	23	23	27	23	26
	Ankle	IR (+)	7	14	3	0	7	4	13	9	10
		ER (-)	23	16	17	30	23	26	17	21	20

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Table 4.11 Number of subjects for the control (C), the un-affected side of the stroke (U), and the affected side of the stroke (A) showing angular displacement of hip, knee, and ankle joints in the sagittal (F = flexion, E = extension, DF = dorsiflexion, PF = plantarflexion), frontal (AB = abduction, AD = adduction), and transverse (IR = internal rotation, ER = external rotation) planes at the fast gait speed at the initial contact (IC), midstance (MS), and toe off (TO)

Plane	Joint	Action	IC Number of subject			MS Number of subject			TO Number of subject		
			C	U	A	C	U	A	C	U	A
Sagittal	Hip	F (+)	30	30	30	19	23	20	2	8	6
		E (-)	0	0	0	11	7	10	28	22	24
	Knee	F (+)	30	30	28	30	30	18	30	30	30
		E (-)	0	0	2	0	0	12	0	0	0
	Ankle	DF (+)	27	27	14	30	29	26	0	3	15
		PF (-)	3	3	16	0	1	4	30	27	15
Frontal	Hip	AB (+)	10	7	13	30	18	24	2	2	8
		AD (-)	20	23	17	0	12	6	28	28	22
	Knee	AB (+)	7	13	20	12	11	18	23	23	27
		AD (-)	23	17	10	18	19	12	7	7	3
	Ankle	AB (+)	27	16	19	30	23	25	18	20	22
		AD (-)	3	14	11	0	7	5	12	10	8
Transverse	Hip	IR (+)	1	6	6	23	13	11	20	17	17
		ER (-)	29	24	24	7	17	19	10	13	13
	Knee	IR (+)	11	10	4	4	6	8	6	10	7
		ER (-)	19	20	26	26	24	22	24	20	23
	Ankle	IR (+)	4	14	11	1	7	5	16	10	8
		ER (-)	26	16	19	29	23	25	14	20	22

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Table 4.12 Comparisons of angular displacements (degrees) in the sagittal, frontal, and transverse planes of the hip, knee, and ankle between the control and the un-affected, the control and the affected, and the un-affected and the affected (n=30) in the comfortable gait speed at the initial contact (IC), midstance (MS), and toe off (TO)

Variable			Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
Plane	**Joint**	**Event**						
Sagittal	**Hip**	**IC**	26.24±5.41	26.46±6.24	18.08±5.77	0.880	0.001*	0.001*
		MS	3.78±5.57	4.82±6.40	1.96±6.28	0.510	0.240	0.024*
		TO	-5.24±6.14	0.45±8.64	-1.49±8.79	0.005*	0.060	0.101
	Knee	**IC**	6.67±3.07	13.92±8.32	8.83±7.27	0.001*	0.140	0.026*
		MS	8.42±3.56	7.13±3.46	2.51±7.79	0.160	0.001*	0.004*
		TO	39.49±3.92	46.00±5.07	29.44±7.63	0.001*	0.001*	0.001*
	Ankle	**IC**	1.67±3.73	1.70±5.03	-0.08±6.55	0.980	0.210	0.258
		MS	8.41±3.61	8.02±2.81	4.58±4.80	0.640	0.001*	0.002*
		TO	-14.40±4.97	-7.36±5.62	1.38±6.30	0.001*	0.001*	0.001*
Frontal	**Hip**	**IC**	0.48±2.44	-2.96±4.40	-0.59±4.60	0.001*	0.270	0.043
		MS	6.05±2.21	0.95±4.30	4.68±4.43	0.001*	0.140	0.002*
		TO	-4.54±3.14	-6.18±4.65	-2.42±4.34	0.110	0.034*	0.003*
	Knee	**IC**	-1.98±3.09	-1.49±4.02	0.41±3.74	0.600	0.009*	0.003*
		MS	-0.71±2.97	-0.96±3.57	0.49±3.61	0.770	0.160	0.007*
		TO	4.65±5.28	5.66±5.94	5.48±4.37	0.490	0.510	0.877
	Ankle	**IC**	0.81±0.86	0.01±2.39	0.04±2.15	0.092	0.079	0.946
		MS	2.28±0.85	1.29±2.19	1.72±2.08	0.025*	0.180	0.415
		TO	0.39±0.96	0.71±2.41	1.16±2.88	0.500	0.170	0.431
Transverse	**Hip**	**IC**	-7.68±6.23	-7.94±12.34	-6.94±8.80	0.920	0.710	0.715
		MS	1.97±3.91	-3.39±10.03	-3.12±8.76	0.010*	0.006*	0.916
		TO	2.80±5.81	3.01±9.05	0.38±7.26	0.910	0.160	0.241
	Knee	**IC**	-3.52±6.88	-5.71±11.86	-7.96±6.91	0.390	0.015*	0.307
		MS	-4.96±4.94	-6.85±9.24	-6.29±7.37	0.330	0.420	0.766
		TO	-6.36±5.87	-6.20±9.35	-7.03±6.97	0.940	0.690	0.706
	Ankle	**IC**	-2.90±4.05	-0.02±9.54	-0.17±8.14	0.140	0.110	0.946
		MS	-8.37±3.63	-4.90±8.92	-6.83±7.55	0.056	0.320	0.373
		TO	-0.99±4.60	-2.69±9.77	-4.45±10.64	0.390	0.110	0.446

Note: * = Significant difference at *p*-value<0.05
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides

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Table 4.13 Comparisons of angular displacements (degrees) in the sagittal, frontal, and transverse planes of the hip, knee, and ankle between the control and the un-affected, the control and the affected, and the un-affected and the affected (n=30) in the fast gait speed at the initial contact (IC), midstance (MS), and toe off (TO)

Plane	Joint	Event	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
Sagittal	**Hip**	**IC**	29.66±5.65	27.70±6.45	19.89±5.71	0.215	0.001*	0.001*
		MS	1.82±6.08	4.63±6.39	1.06±6.94	0.086	0.653	0.006*
		TO	-9.71±7.57	-2.61±8.87	-4.26±8.69	0.001*	0.012*	0.138
	Knee	**IC**	9.11±3.47	14.89±9.00	10.66±7.81	0.002*	0.326	0.080
		MS	8.92±3.60	8.18±4.17	2.77±8.47	0.464	0.001*	0.001*
		TO	38.88±4.21	45.27±5.15	29.86±7.61	0.001*	0.001*	0.001*
	Ankle	**IC**	3.52±3.38	3.12±2.88	0.32±6.63	0.623	0.023*	0.036*
		MS	10.04±3.50	8.94±3.24	5.10±4.63	0.212	0.001*	0.001*
		TO	-18.25±5.60	-8.04±9.21	-0.25±7.03	0.001*	0.001*	0.001*
Frontal	**Hip**	**IC**	-0.87±3.56	-3.14±4.43	-0.85±5.35	0.033*	0.984	0.059
		MS	6.05±2.20	1.31±4.40	4.46±5.48	0.001*	0.149	0.017*
		TO	-5.50±3.52	-6.17±4.44	-2.60±4.60	0.521	0.008*	0.006*
	Knee	**IC**	-1.95±3.20	-1.72±4.14	1.06±4.01	0.807	0.002*	0.001*
		MS	-0.60±2.91	-1.12±3.51	0.61±3.87	0.537	0.176	0.002*
		TO	3.34±5.62	5.68±5.65	5.86±5.55	0.114	0.086	0.892
	Ankle	**IC**	1.11±1.03	0.22±2.44	0.30±2.01	0.073	0.056	0.880
		MS	2.44±1.07	1.25±2.38	1.68±2.21	0.017*	0.098	0.454
		TO	0.40±1.33	0.70±2.54	1.39±2.86	0.573	0.094	0.305
Transverse	**Hip**	**IC**	-8.55±5.62	-8.73±11.97	-4.42±16.39	0.941	0.200	0.225
		MS	3.11±3.78	-3.30±10.02	-3.08±10.43	0.002*	0.004*	0.941
		TO	1.42±6.56	2.64±9.05	1.71±9.40	0.555	0.891	0.725
	Knee	**IC**	-1.87±6.37	-5.14±12.21	-8.08±7.48	0.199	0.001*	0.241
		MS	-5.27±5.15	-6.36±9.33	-5.93±7.95	0.580	0.705	0.830
		TO	-4.29±7.01	-6.46±10.37	-6.31±8.18	0.347	0.308	0.952
	Ankle	**IC**	-4.20±4.88	-0.77±10.02	-1.01±7.67	0.099	0.061	0.906
		MS	-9.05±4.94	-4.76±9.66	-6.57±7.72	0.036*	0.145	0.420
		TO	-1.01±6.09	-2.55±10.22	-5.22±10.45	0.480	0.063	0.305

Note: * = Significant difference at p-value<0.05
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides

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4.3.2.2 Angular velocity (degrees/sec)

Five peak angular velocities composed of the hip velocity during the initial swing (H), knee velocity during the initial swing (K1) and the terminal swing (K2), and the ankle velocity during the initial swing (A1) and the midswing (A2). The angular velocity of the hip, knee, and ankle in the sagittal plane of control, the affected side of the stroke, and the un-affected side of stroke both in the comfortable and fast gait speeds were exhibited in Figures 4.10-4.12. In the angular velocity graphs, the X-axis presents the % gait cycle and the Y-axis presents the velocity (degrees/s). In the sagittal plane, the positive value represents the velocities of the hip and knee flexion and ankle dorsiflexion. The negative value represents the velocities of the hip extension, knee extension and ankle plantarflexion.

From Figures 4.10-4.12, it was found that the patterns of angular velocity of all joints in the control were smoother than the stroke in both the comfortable and fast gait speeds. For the peak angular velocity, the stroke had less angular velocity than that of the control in all joints. In addition, the stroke showed less angular velocity in the affected side than the un-affected side.

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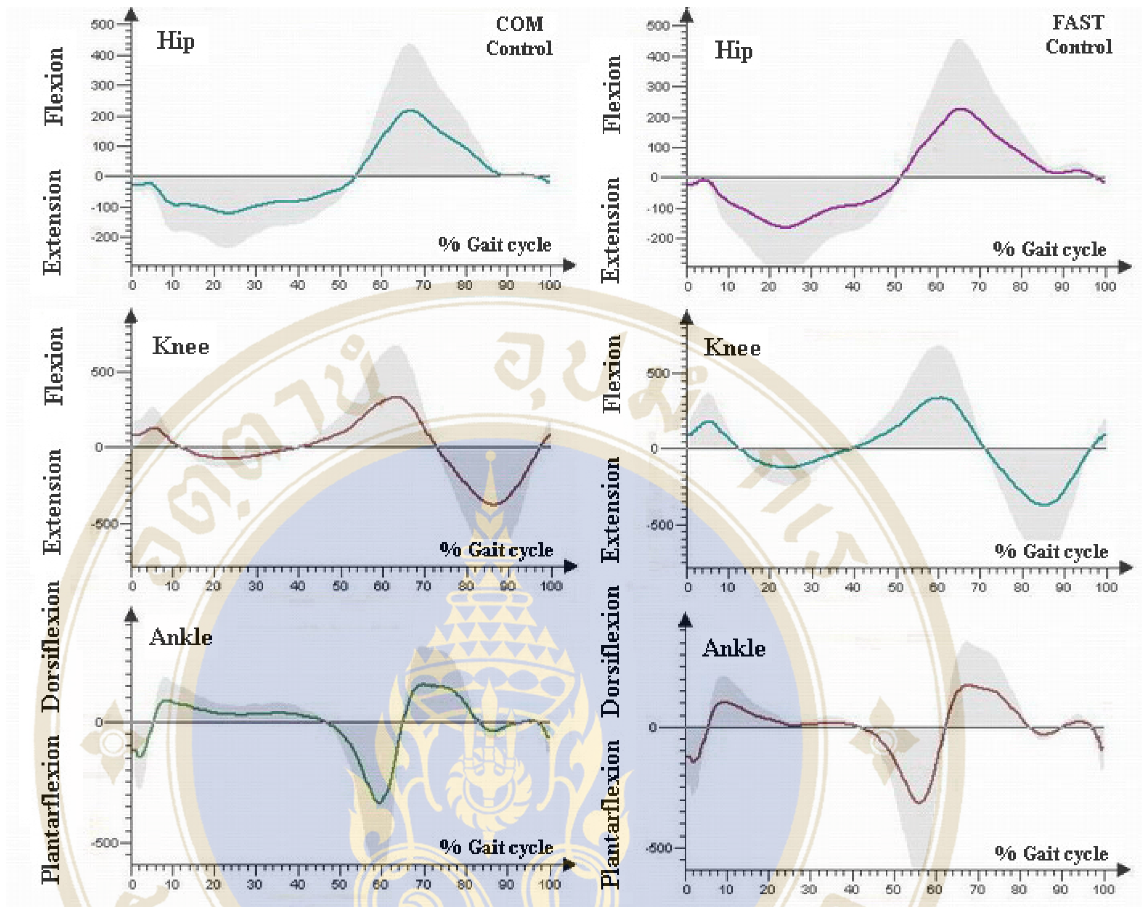

Figure 4.10 Angular velocities (degrees/s) in the sagittal plane of the hip, knee, and ankle of the control at comfortable (COM) and fast (FAST) gait speeds.

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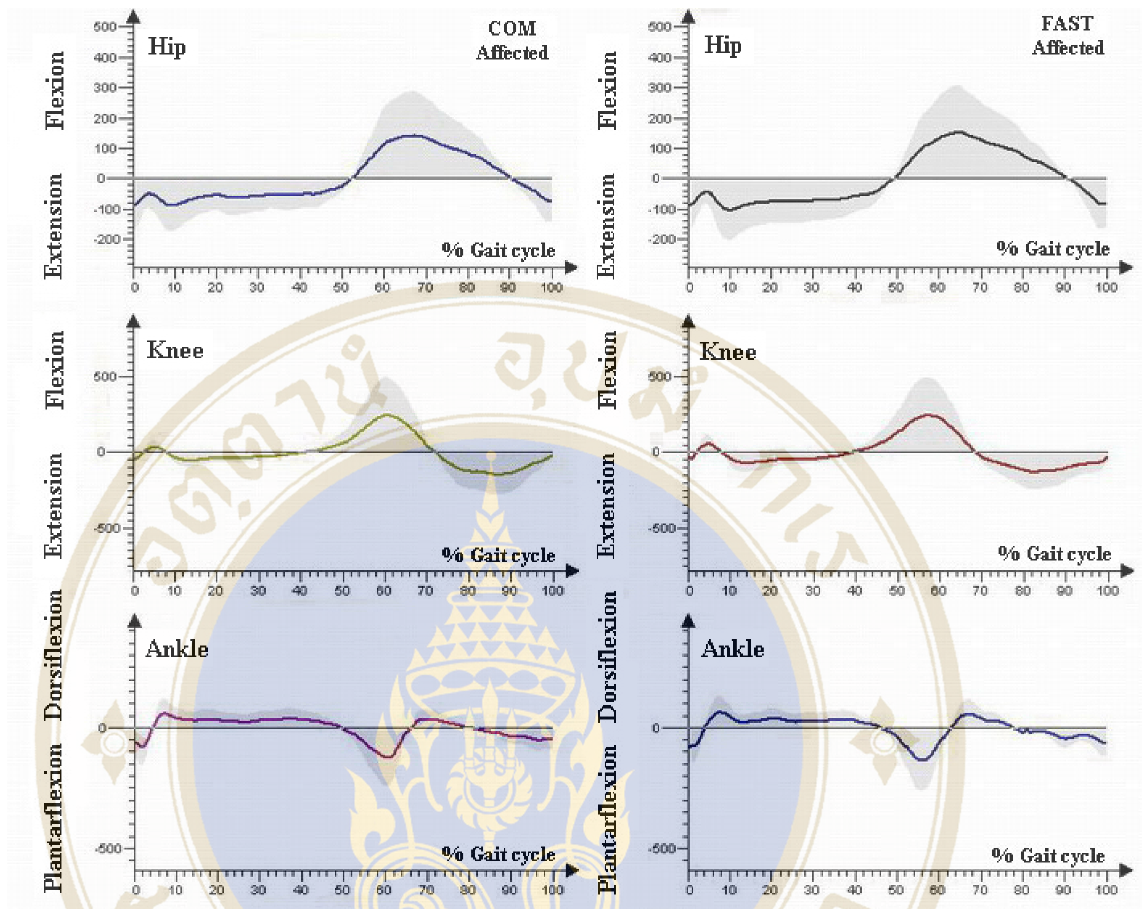

Figure 4.11 Angular velocities (degrees/s) in the sagittal plane of the hip, knee, and ankle of the affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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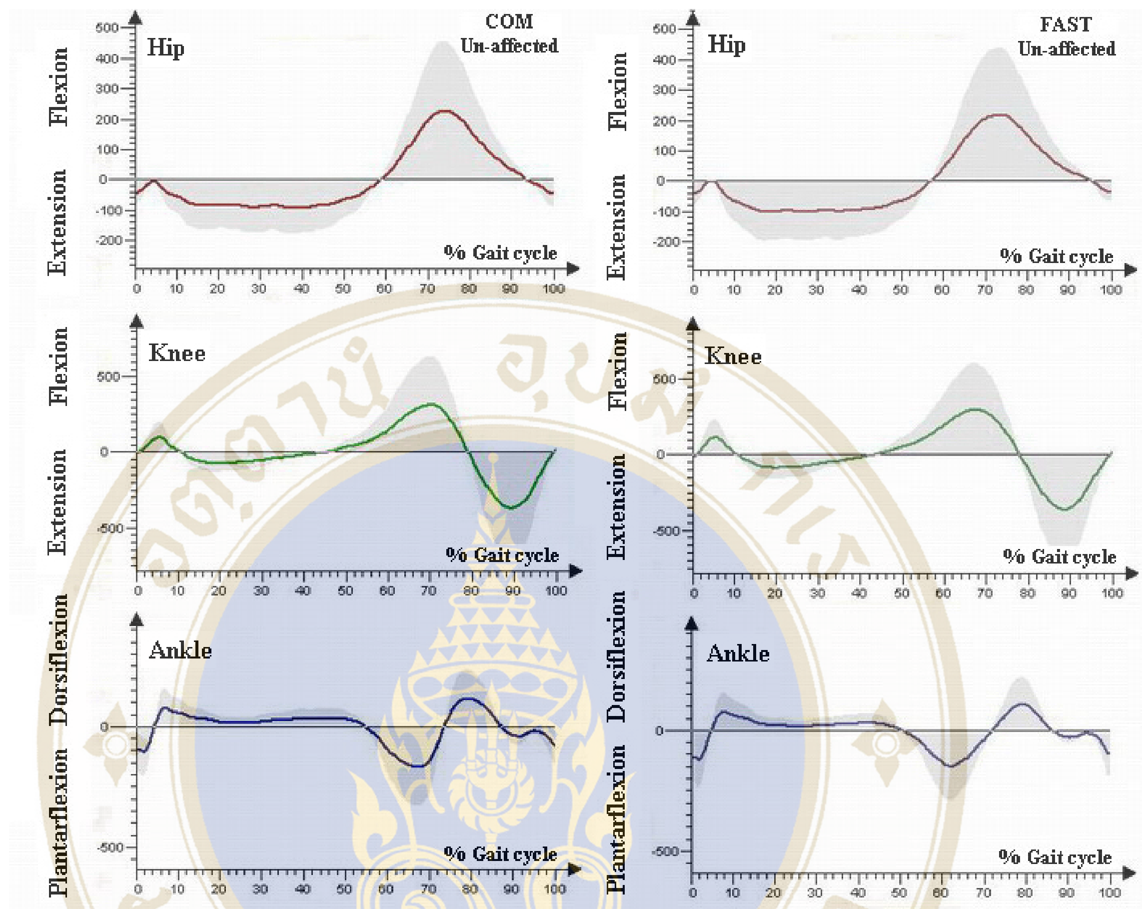

Figure 4.12 Angular velocities (degrees/s) in the sagittal plane of the hip, knee, and ankle of the un-affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

Table 4.14 presents the number of subjects for the control, the affected side of the stroke, and the un-affected side of the stroke showing peak angular velocity The positive sign represents flexion of the hip and knee joints and dorsiflexion of the ankle joint and negative sign represents extension of the hip and knee joints and plantarflexion of the ankle joint. Both the control and the stroke demonstrated consistent results. The peak angular velocity of the hip, knee, and ankle in the sagittal plane were compared between the stroke and control groups as well as between the affected and the un-affected sides of the stroke as shown in Table 4.15. Peak angular velocity between the control and the un-affected side of the stroke showed significant differences both in comfortable and fast speeds for the hip flexion, knee flexion, and ankle plantarflexion velocities during the initial swing. The comparisons between the

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control and the affected side of the stroke and between the un-affected and the affected sides of the stroke demonstrated significant differences in peak angular velocity of all joints at both gait speeds.

Table 4.14 Number of subjects for the control (C), the un-affected side of the stroke (U), and the affected side of the stroke (A) showing peak angular velocity (H = Hip velocity during initial swing, K1 = Knee velocity during initial swing, K2 = Knee velocity during terminal swing, A1 = Ankle velocity during initial swing, and A2 = Ankle velocity during midswing) of the hip, knee, and ankle in the sagittal plane (F (+) = Flexion, E (-) = Extension, DF (+) = Dorsiflexion, and PF (-) = Plantarflexion) at comfortable and fast (FAST) gait speeds

Comfortable gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
H	**C**	**U**	**A**	**K1**	**C**	**U**	**A**	**A1**	**C**	**U**	**A**
F (+)	30	30	30	F (+)	30	30	30	DF (+)	0	0	0
E (-)	0	0	0	E (-)	0	0	0	PF (-)	30	30	30
				K2	**C**	**U**	**A**	**A2**	**C**	**U**	**A**
				F (+)	0	0	0	DF (+)	30	30	30
				E (-)	30	30	30	PF (-)	0	0	0
Fast gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
H	**C**	**U**	**A**	**K1**	**C**	**U**	**A**	**A1**	**C**	**U**	**A**
F (+)	30	30	30	F (+)	30	30	30	DF (+)	0	0	0
E (-)	0	0	0	E (-)	0	0	0	PF (-)	30	30	30
				K2	**C**	**U**	**A**	**A2**	**C**	**U**	**A**
				F (+)	0	0	0	DF (+)	30	30	30
				E (-)	30	30	30	PF (-)	0	0	0

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Table 4.15 Comparisons of peak angular velocity (H = Hip velocity during initial swing, K1 = Knee velocity during initial swing, K2 = Knee velocity during terminal swing, A1 = Ankle velocity during initial swing, and A2 = Ankle velocity during midswing) (degrees/sec) of the hip, knee, and ankle between the control and the un-affected of the stroke, the control and the affected sides of the stroke, and the un-affected and the affected sides of the stroke (n=30) in the comfortable (COM) and fast (FAST) gait speeds

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
H	COM	224.81±22.72	261.05±27.62	178.17±39.94	0.001*	0.001*	0.001*
	FAST	236.29±25.23	261.83±29.50	181.20±39.45	0.001*	0.001*	0.001*
K1	COM	350.83±32.55	389.05±45.55	300.61±75.43	0.001*	0.002*	0.001*
	FAST	357.38±33.56	383.89±43.98	305.27±76.84	0.011*	0.002*	0.001*
K2	COM	-389.48±51.53	-400.57±64.57	-218.52±91.18	0.465	0.001*	0.001*
	FAST	-389.30±39.12	-401.85±68.08	-208.72±78.84	0.386	0.001*	0.001*
A1	COM	-374.95±58.84	-312.25±72.13	-168.29±82.21	0.001*	0.001*	0.001*
	FAST	-364.98±65.69	-310.50±79.84	-176.26±77.00	0.005*	0.001*	0.001*
A2	COM	167.61±43.04	177.57±59.05	81.56±54.53	0.458	0.001*	0.001*
	FAST	188.79±62.94	183.22±57.23	86.06±48.75	0.721	0.001*	0.001*

Note: * = Significant difference at *p*-value<0.05
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides

4.3.3 Ground reaction forces (%BW)

Ground reaction forces (GRFs) of the medio-lateral (X), antero-posterior (Y), and vertical (Z) directions were determined in the present study. Seven peak GRFs composed of three GRFs of the medio-lateral direction: X1, X2, X3; two in the antero-posterior direction: Y1, Y2; two in the vertical direction: Z1, Z2 were investigated (Figure 4.13). Individual body weight was normalized to GRFs data before comparison.

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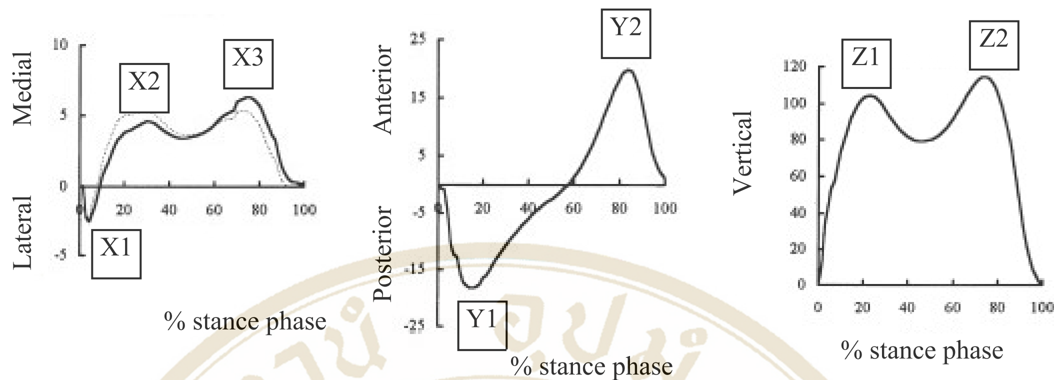

Figure 4.13 Ground Reaction forces (%BW) in the medio-lateral (X1 = first peak lateral force, X2 = first peak medial force, and X3 = second peak medial force), antero- posterior (Y1 =braking peak force, Y2 = propulsion peak force), and vertical (Z1 = first peak vertical force, Z2 = second peak vertical force) directions**.**

Patterns of ground reaction forces in the medio-lateral, antero-posterior, and vertical of thirty control and thirty stroke subjects in the comfortable and fast gait speeds are shown in Figures 4.14-4.16. In the GRFs graphs, the X-axis presents time consumed during walking (% gait cycle) and the Y-axis presents the force (% BW).

The curves in the control were smoother than those in the stroke in both the affected and un-affected sides. Moreover, greater force production was expressed in the control than the stroke as shown in Figures 4.14-4.16. Number of subjects of each group showing GRFs in the medio-lateral (X1, X2, X3), antero-posterior (Y1, Y2), and vertical (Z1, Z2) directions at comfortable and fast gait speeds are presented in Table 4.16. All control subjects expressed the GRFs in the same direction, whereas, the stroke had abnormal GRFs especially in the medio-lateral direction.

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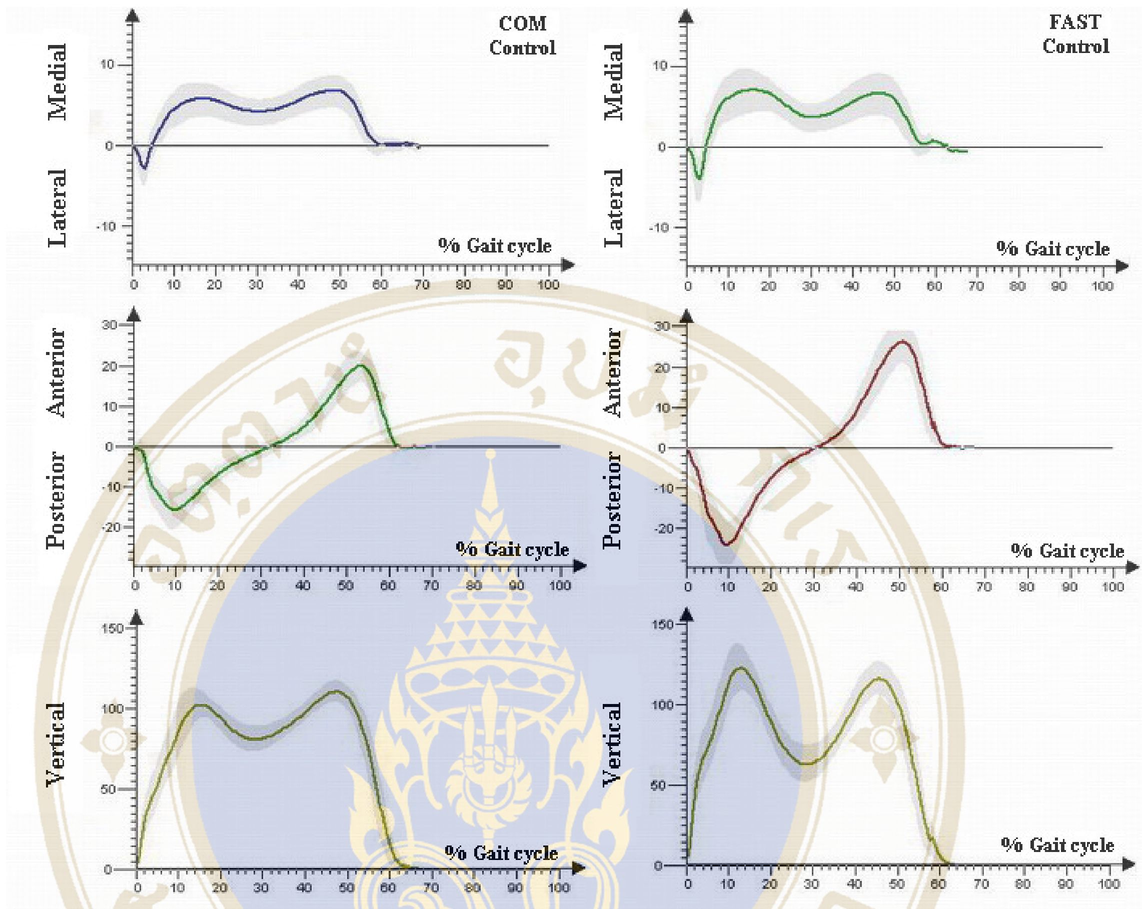

Figure 4.14 Ground reaction forces (%BW) in the medio-lateral (X), antero-posterior (Y), and vertical (Z) axes of the control at comfortable (COM) and fast (FAST) gait speeds.

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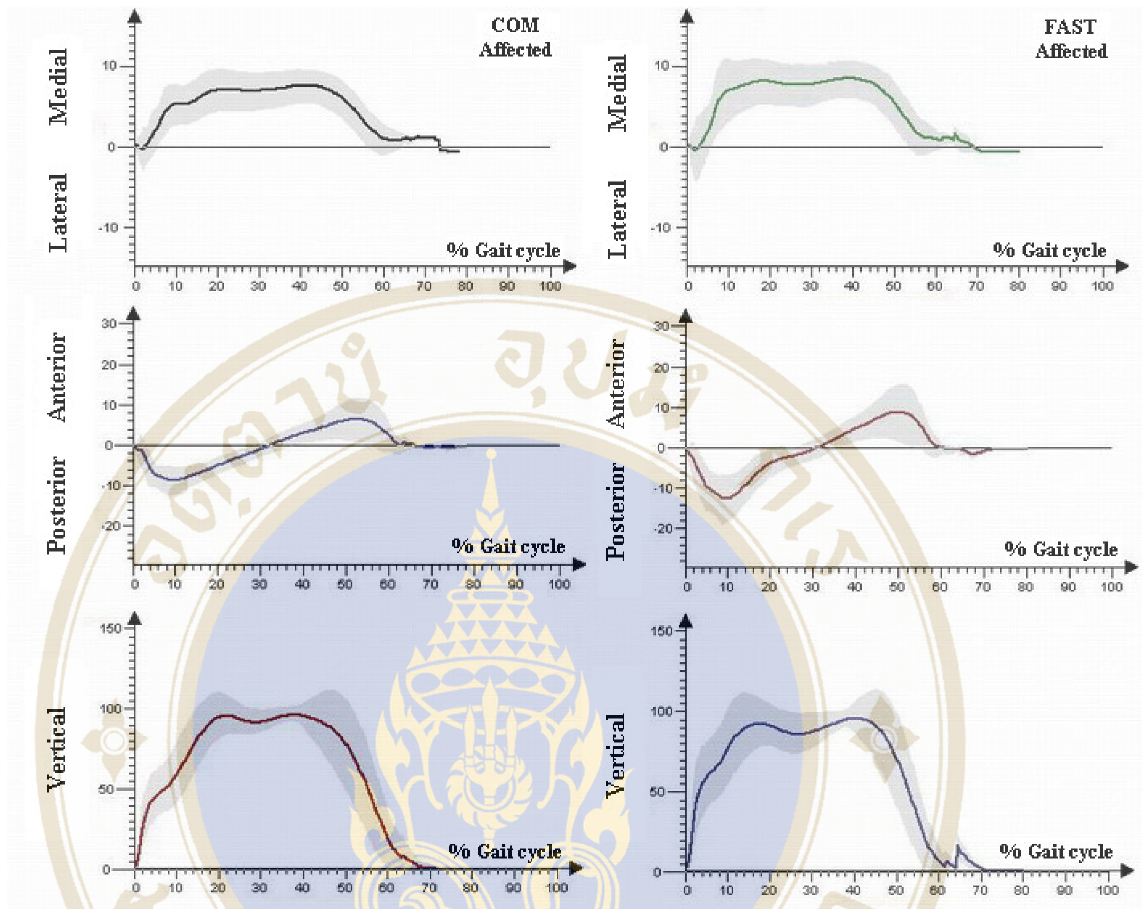

Figure 4.15 Ground reaction forces (%BW) in the medio-lateral (X), antero-posterior (Y), and vertical (Z) axes of the affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

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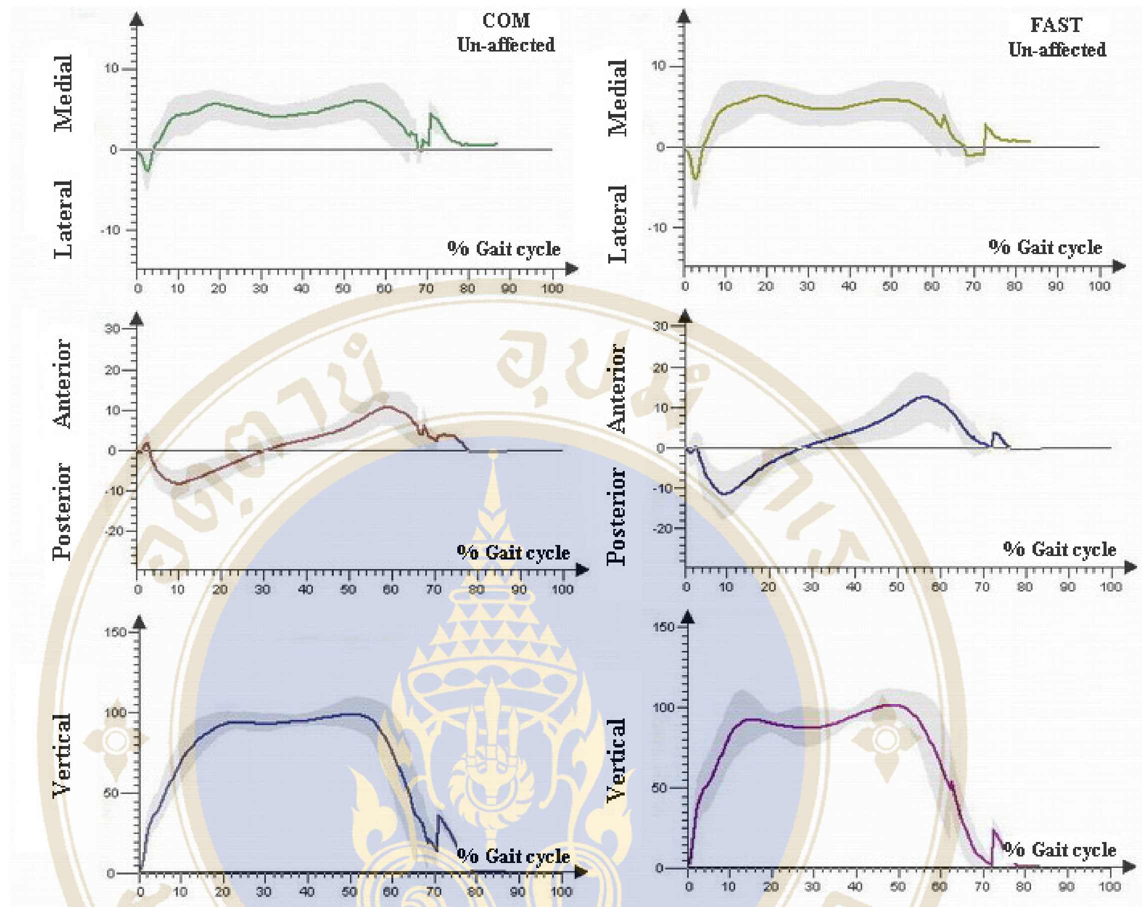

Figure 4.16 Ground reaction forces (%BW) in the medio-lateral (X), antero-posterior (Y), and vertical (Z) axes of the un-affected side in the stroke at comfortable (COM) and fast (FAST) gait speeds.

GRFs data were compared between the control and the affected side of the stroke and between the control and the un-affected side of the stroke, as well as between the un-affected and the affected sides of the stroke (Table 4.17). There were significant differences in GRFs between the control and the un-affected side of the stroke in the Y1, Y2, Z1, and Z2 in both the comfortable and fast gait speeds. Comparisons between the control and the affected side of the stroke found significant differences in all GRFs data, except the Z1 at the comfortable speed. Between the un-affected and the affected sides of the stroke, there were significant differences in GRFs in all comparisons, except the Y1 at both gait speeds, Z1 at the fast gait speed, and Z2 at the comfortable gait speed.

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Table 4.16 Number of subjects for the control (C), the un-affected side of the stroke (U), and the affected side of the stroke (A) showing GRFs in the medio-lateral (X1, X2, X3), antero-posterior (Y1, Y2), and vertical (Z1, Z2) directions at comfortable and fast gait speeds

Comfortable gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
X1	**C**	**U**	**A**	**Y1**	**C**	**U**	**A**	**Z1**	**C**	**U**	**A**
Medial (+)	0	1	19	Propulsive (+)	0	0	0	Vertical (+)	30	30	30
Lateral (-)	30	29	11	Braking (-)	30	30	30	(-)	0	0	0
X2	**C**	**U**	**A**	**Y2**	**C**	**U**	**A**	**Z2**	**C**	**U**	**A**
Medial (+)	30	10	30	Propulsive (+)	30	30	30	Vertical (+)	30	30	30
Lateral (-)	0	0	0	Braking (-)	0	0	0	(-)	0	0	0
X3	**C**	**U**	**A**								
Medial (+)	30	10	30								
Lateral (-)	0	0	0								
Fast gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
X1	**C**	**U**	**A**	**Y1**	**C**	**U**	**A**	**Z1**	**C**	**U**	**A**
Medial (+)	0	1	11	Propulsive (+)	0	0	0	Vertical (+)	30	30	30
Lateral (-)	30	29	19	Braking (-)	30	30	30	(-)	0	0	0
X2	**C**	**U**	**A**	**Y2**	**C**	**U**	**A**	**Z2**	**C**	**U**	**A**
Medial (+)	30	30	30	Propulsive (+)	30	30	30	Vertical (+)	30	30	30
Lateral (-)	0	0	0	Braking (-)	0	0	0	(-)	0	0	0
X3	**C**	**U**	**A**								
Medial (+)	30	30	30								
Lateral (-)	0	0	0								

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Table 4.17 Comparisons of ground reaction forces (% body weight) in the medio-lateral (X1 = first peak lateral force, X2 = first peak medial force, and X3 = second peak medial force), antero- posterior (Y1 =braking peak force, Y2 = propulsion peak force), and vertical (Z1 = first peak vertical force, Z2 = second peak vertical force) directions between the control and the un-affected, the control and the affected, and the un-affected and the affected at the comfortable (COM) and fast (FAST) gait speeds

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
X1	COM	-3.32±1.23	-3.19±1.98	-1.29±1.88	0.770	0.001*	0.001*
	FAST	-4.75±1.78	-4.71±3.14	-2.14±2.98	0.960	0.001*	0.001*
X2	COM	6.28±1.68	6.05±1.90	7.86±3.04	0.627	0.016*	0.002*
	FAST	7.85±2.13	6.93±2.11	9.45±2.78	0.097	0.016*	0.001*
X3	COM	7.07±1.50	7.08±2.09	8.54±2.29	0.987	0.005*	0.001*
	FAST	7.11±1.96	7.02±2.13	9.19±2.29	0.866	0.001*	0.001*
Y1	COM	-16.10±4.10	-9.46±3.30	-9.90±3.11	0.001*	0.001*	0.526
	FAST	-24.52±5.58	-12.51±5.66	-14.11±5.71	0.001*	0.001*	0.128
Y2	COM	20.86±3.30	13.08±4.23	8.10±4.79	0.001*	0.001*	0.001*
	FAST	27.95±4.32	16.45±5.32	10.84±6.42	0.001*	0.001*	0.001*
Z1	COM	105.66±7.01	99.48±3.11	104.03±5.88	0.001*	0.331	0.001*
	FAST	124.48±12.98	101.87±10.17	104.94±10.05	0.001*	0.001*	0.130
Z2	COM	112.06±5.29	103.57±5.64	102.40±3.87	0.001*	0.001*	0.169
	FAST	118.26±9.07	106.46±8.20	102.65±6.47	0.001*	0.001*	0.008*

Note: * = Significant difference at *p*-value<0.05
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides

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CHAPTER V
DISCUSSION

5.1 Subject Characteristics

In the present study, there were 30 subjects in each of the control and the stroke groups. Both groups included 5 males and 25 females. There were no differences in age, body weight, and height between the control and the stroke, as shown in Table 4.1. Therefore, in the present study, the gender, body weight, and height are not expected to affect the gait characteristics as the previous findings reported about effects of gender (146, 147), age (148, 152-156), body weight and height (172), and gait speed (161, 162) on gait characteristics. Furthermore, the stroke participated in the present study were able to walk independently without using any assistive devices. Therefore, the control and the stroke walked in the similar feature during collecting data.

For the stroke group, the cognitive deficit, muscle tone, motor function, and postural balance were evaluated. In the present study, the stroke showed no deficit in the cognitive state. They participated and understand in the whole process of the study. For the muscle tone, five muscle groups of lower extremity were evaluated because these muscle groups cooperate together during walking (68, 173, 174) and these muscles usually show an alteration in muscle tone when moving (175-177). An increase in lower extremity muscle tone interfered on motor and activity performance (10, 129, 178-182). Therefore, the evaluation and the representation of muscle tone in the stroke were necessary show. In the current study, in addition to evaluation of muscle tone in the affected lower limb, the motor functions were also assessed. The stroke showed a wide range of lower limb motor function, ranging from moderate to high scores. This is partly due to the muscle tone of these five muscle groups.

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Two stroke subjects showing no increases in muscle tone were able to perform motor function perfectly, and from the observation of gait pattern, they walked nearly resemble to the typical pattern of the control. For postural balance, the stroke were assessed for both the affected and the un-affected legs in some items since the stroke usually use the un-affected side in performing the activities and movements (134, 183). In the present study, it is not surprising that the stroke has higher score in the un-affected side than in the affected side. However, all stroke subjects showed good postural balance performance either in the affected side or in the un-affected side as demonstrated with the score of BBS for the affected and the un-affected of 49.47±3.69, ranging from 40-55 and 51.67±3.2, ranging from 45-56, respectively .

5.2 Correlations between Clinical Measures and Gait Performances

From the literatures review, the outcome measures which frequently used to indicate the gait performance were the self-paced gait speed, temporo-spatial, and fast gait speed (184). Gait speed is widely used as the outcome measure to monitor the effect of stroke and the changes during rehabilitation (18, 119, 184, 185). Gait speed was recommended to use in independently walking patients (119). However, gait speed can provide the information only the quantitative aspect of walking performance. Recently, qualitative gait characteristics were suggested for investigating and using in interpreting the stage of patient movement (49, 52, 64). Furthermore, a pronounced asymmetrical deficit is typical characteristic for hemiparetic gait. The asymmetrical gait pattern includes decreased stance time, prolonged swing period of the affected limb, and more weight bearing toward the un-affected limb (19, 48, 49). Therefore, the present study determines the quantitative and qualitative gait performances by gait speed and symmetry concomitantly. In addition, both gait speed (28, 40, 184, 185) and gait symmetry (19, 47, 48, 64) were frequently used as the outcome measures in classifying an ability of gait in patients with stroke because of convenient, practical, easy to interpret, and useful for rehabilitation (31, 119). In patients with stroke, abnormal movement pattern are resulted from many causes. Impaired motor function, balance, and deviation of muscle tone were mentioned as the important elements involving the movement and relating to gait performance in the

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stroke (10, 12, 21, 25, 54, 58, 101, 128, 129). Therefore, the clinical measures such as motor function, balance, and muscle tone were quantified and were determined the relationship with the gait performances as speed and symmetry.

5.2.1 Correlations between clinical measures and gait speeds

The relationships between clinical measures: MAS of the hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors, BBS for the affected side and un-affected side of the stroke, and FMA of the lower extremity and two gait speeds: comfortable and fast were determined in the present study.

- Correlations between the MAS and gait speeds

The relationship between tone of lower extremity muscles and gait speed is controversial. Several studies investigated on the ankle plantarflexors and knee extensors based on the assumption of their importance during walking. There were reported no significant relationship between spasticity of these muscles and gait speed (12, 13, 16, 40, 186). In addition, the other muscle groups such as hip adductors, hip extensors, and ankle invertors were not reported to have relationship with gait speed. Therefore, it is interesting to investigate these muscle groups since the normal walking require the functional co-operative of overall lower extremity muscles (174, 187). Spasticity investigation in several muscle groups (hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors) was found to relate to the comfortable and fast gait speeds as reported with the significant negative relationships (r_s = -0.387 to -0.569) in the present study. It is indicated that both comfortable and fast gait speeds are reduced when patients with stroke have increase in muscle tone of these muscles.

Similar to the previous studies (49, 128), the ankle plantarflexors spasticity was stated to be a factor contributing to poor locomotion performance after stroke. The spasticity of the affected ankle plantarflexors was reported as the second most important determinance of comfortable gait speed in patients who have stroke (49). The results of Lamontagne in 2001 (128), reported the negative relationship of ankle plantarflexors spasticity with gait speed in the stroke.

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Thus, the less the spasticity was, the comfortable gait speed was faster. Confirmation of influence of ankle plantarflexors spasticity to gait was done by the therapeutic intervention in the previous studies (188, 189). In patients post stroke, it was found that the botulinum toxin can reduce the muscle tone and premature activity of the spastic plantarflexors during the terminal swing and early stance of the gait cycle (188, 189). Increasing of tone in lower extremity muscle groups which detected from the present study may inhibit the gait speed. Dynamic equines deformity of the ankle from calf muscle spasticity can impede toe clearance during the swing phase of gait causing increase the risk of fall in these patients. The presence of spasticity and clonus may have a direct effect on walking by affecting foot placement during standing, causing reduction of postural stability. Occurrence of hypereactive stretch reflex during the early stance phase of gait may impede the walking capacity and therefore the gait speed will decrease (119, 190). Inappropriate activity in the intrinsic muscles of the foot and long toe flexors is reported to be the additional causes of painful toe flexion and the difficulty of walking (190).

Besides the apparent relationships of ankle plantarflexors spasticity and gait speed, further discovery in the hip adductors, hip extensors, knee extensors, and ankle invertors were found in the present study demonstrating that these muscle tones were important for walking at both comfortable and fast gait speeds. For the importance of hip adductor tone, overactivity of the muscle can impede walking ability during step as demonstrated in the cerebral palsy and scissor gait conditions (123, 124). In the present study, although the adductor tone in the stroke was not greatly increased, it negatively related to both comfortable (r_s = -0.471) and fast (r_s = -0.427) gait speeds.

Hip extension during walking in the stroke comparing to the control was diminished in both the comfortable and fast gait speed as illustrated in Figures 4.1-4.3. It may be caused by the deviation in muscle tone, the increase in tone of hip extensor muscle possibly interfere walking during the terminal stance and intervene normal step. It was found that the relationships of hip extensors and gait

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speeds were moderate (r_s = -0.490 for the comfortable and r_s = -0.469 for the fast gait speeds).

Knee extensors functions plays an important role for both stance and swing periods of gait. Slight knee bending during the early stance phase is necessary for normal walking for shock absorbing function (126). If this action is loss, the knee may hyperextend as commonly exhibited in the patients with stroke. During the midswing and the terminal swing, the knee has concentric and eccentric contractions, respectively. Loss of knee function during the stance phase may lead to loss of stability of the knee and then affects the overall postural control of the body. Diminished knee extension during the swing can cause a shorter step length. Thus, spasticity of knee extensors influences the gait speed. However, it was found that the relationships of knee extensors muscle tone and gait speed were only mild to moderate (r_s = -0.387 for the comfortable and r_s = -0.427 for the fast gait speed).

High degrees of relationships of muscle tone and gait speed were found in the ankle muscle groups. In the present study, the ankle plantarflexors were found to be related with gait speed at r_s = -0.536 for the comfortable and r_s = -0.529 for the fast gait speed. In addition, the ankle invertors had significant relationship with gait speed at r_s = -0.528 for the comfortable and r_s = -0.569 for the fast gait speed.

Several studies did not found the relationship of spasticity and gait speed (12, 13, 16, 40, 186). Their failure to find significant tone-gait speed relationship might be due to several reasons. For instance, the different method in quantifying the tone of muscle, degree of increased tone, stage of recovery of the subject, and number of subject. By using the spasticity scale proposed by Levin and Hui-Chan method, Nadeau et al (40) did not found a significant correlation (r = -0.009, p = 0.05) between the spasticity of the affected ankle plantarflexors and comfortable gait speed of patients with mild to moderate stroke. There was also reported no relationship of the knee extensors and gait speed in previous studies (12, 13, 16, 186), by using the isokinetic torque method (186) and the relative angle of

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reversal (RAR) of the Cybex electrogoniometer curve obtained with the pendulum tests (13).

Thus, the technique used to assess the tone of muscle should be realized. In the present study, the MAS was selected to test the lower extremity muscle tone in the stroke during the supine lying position which is the relaxation position. However, the muscle tone in the stroke can be changed by the testing position (55) and viscoelastic property changes (182, 191). Thus, the relationships of the tone of muscle and gait speed existed in the present study indicating the effect of tone which tested in the relaxed resting position to gait performance.

- **Correlations between the BBS and gait speeds**

From the previous results, gait speed was reported to be related to the BBS score (119). According to the present results, it was found that both comfortable and fast gait speeds were significant related with the BBS score for the affected side, but not for the un-affected. It can be interpreted that, the better postural balance in the affected side is, the faster gait speed is. Control of balance during performing the fourteen functional balance items in the BBS for the affected leg are related to the gait speed in patients with stroke. Good postural balance control in the affected side of the stroke assists gait speed when walking. The reason is that walking requires a complex postural control, which both legs alternatively work together dynamically. If the stroke shows poor postural balance during standing on the affected leg, or show difficulty in movement in the affected leg, they should take longer time for walking. The shorter single support time during walking in the stroke comparing to the control is an evidence showing poor balance on the affected leg, thus, influencing gait speed (23).

However, the relationships between BBS for the affected side and both comfortable and fast gait speeds (r_p = 0.398 and r_p = 0.400, p<0.05) demonstrating in the present study were somewhat low comparing to the other studies (40, 192, 193). Harris et al in 2005 (193), demonstrated high degree of relationships of BBS score and comfortable and fast gait speeds (r = 0.74 and r = 0.70, p<0.01). Some

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items of BBS score were related to the gait speed at the early stage post stroke as reported by Langhammer et al in 2006 (192), Their results showed higher relationship of BBS-item 6 (standing with blindfold) and BBS-item 8 (reaching) with gait speed at the admission stage (r_s = 0.82 for the BBS-item 6, r_s = 0.60 for the BBS-item 8) than the discharge stage (r_s = 0.53 for the BBS-item 6, r_s = 0.47 for the BBS item-8). Degree of recovery of stroke demonstrated to be the factor implementing the altering gait performance.

None of the previous studies investigated the BBS score separating in the affected and the un-affected sides. Therefore, the present study is the first providing the BBS score in the individual affected and un-affected side in the stroke. In addition, the results of correlation between the BBS score and the other clinical measures will give more information from previously. As reported from the present study, there was no significant correlation between the BBS score for the un-affected side and both gait speeds. It can be stated that in the stroke the balance in the un-affected side does not relate to gait speed. Therefore, the present study suggests that in the stroke, the balance and movement in the affected leg is an important factor influencing on gait speed. The other suggestion is that the postural balance test should be tested separately on either the affected side or the un-affected side.

- Correlations between the FMA and gait speeds

Similar to the other studies (16, 33, 40, 119), significant relationships of FMA and gait speeds were also found to be positive. Gait speed of patients with mild to moderate stroke was found to correlate significantly with the motor recovery status of the affected lower extremity, as rated by Brunnstrom stages (r = 0.88) (33) or by the lower motor subscale of the FMA (r = 0.61) (40). It is indicated that patients with stroke who have good lower extremity motor function will have good gait speed.

Among three clinical measures tested (muscle tone, balance, and motor function) in the present study, motor function assessing by the FMA was related with the gait speed at the highest level (r_p = 0.631 and r_p = 0.610 for the

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comfortable and fast gait speeds, $p<0.05$). It is interpreted that the motor function might play a decisive role and necessary for walking in the case of speed improving in the stroke.

The FMA is the motor function test which is usually used for detecting the recovery of motor function in the stroke and useful for clinical assessment in comparative analysis of the effectiveness of various therapeutic interventions. A measurement of recovery of function following cerebrovascular accident has been developed by Fugl-Meyer et al in 1975 (57). The FMA of physical performance is a cumulative numerical scoring system for measurement of motor recovery, balance, sensation, joint range of motion, coordination, and speed of movement in patients who have sustained cerebrovascular accident. Kang et al in 2005 (25) reported that the FMA correlated positively with the maximum and minimum angle of knee flexion and the maximum angle of ankle dorsiflexion. Because the segmental movement is a part of gait speed, the FMA is expected to be related with gait speed.

Furthermore, the FMA was also reported to relate with the other variables, for instance, the affected lower extremity muscle strength (14), stride length (14), and COP-COM amplitudes of the antero-posterior and medio-lateral directions during standing (121). It is implied that the stroke who have lower motor performances exhibit greater postural instability (121). Hence, the findings of the present study and the previous studies support the notion that motor function is related to the gait performance by directly impact and inter-relationship of balance control.

5.2.2 Correlations between clinical measures and gait symmetry

The asymmetrical nature of hemiparetic walking is well documented in persons who have sustained a stroke (19, 33), with the asymmetries in temporo-spatial, kinematic, and kinetic parameters of gait related to disturbances of motor control (115). Asymmetry in temporo-spatial has been commonly used in clinic to examine the gait characteristic in patients who experienced hemiparesis. Previous studies (33) have reported that the temporal asymmetry is a significant predictor of hemiparetic

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walking performance because it strongly correlates with the stages of motor recovery and walking speed. However, the existing data involving the relationships between other parameters such as spatial, kinematic, and kinetic and the gait performance in the stroke are still very limited.

In normal gait, symmetrical gait pattern has been assumed to be existed (50, 84). Symmetrical gait characteristic was expected to improve among patients with stroke after rehabilitation (36, 43). It is found that gait pattern changed over a period of time. From the study of Turnbull and Wall in 1995 (7), gait pattern changed in the patients with stroke over 10 years, showing a decrease in stride time and length, but no change in gait speed. In addition, support phase was altered with the extended time spent on the un-affected side and shorter time spent on the affected side. Stroke subjects had more asymmetrical gait pattern over long time period. Consequently, gait symmetry was proposed to be the additional unredundant information about therapeutic effects which cannot be gained by the measurement of gait speed alone (194) and can provide an important clinical detector of recovery and functionality during training (19, 48, 49, 52).

The present study selected six symmetrical gait variables relating to the temporo-spatial and force parameters for indicating the symmetrical gait pattern in patients with stroke. The symmetrical gait variables consisted of the first peak vertical force, the second peak vertical force, single support time, step time, stance time, and swing time. The present results found that only two gait symmetrical variables (stance time and swing time) presented consistent pattern in all 30 patients with stroke (Table 4.4). Stance time expressed the negative value, indicated the un-affected side had longer stance time than the affected side did. In contrast, the swing time expressed the positive value, indicated the affected side had longer swing time than the un-affected side did. For the remaining gait symmetrical variables (the first peak vertical force, the second peak vertical force, single support time, and step time), the stroke demonstrated inconsistent pattern of the performance of the affected and the un-affected sides. Likewise, the inconsistent pattern also demonstrated in the distance

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parameter of the step length as reported in the stroke walking with either relatively longer affected or un-affected steps (37, 49).

- Correlations between clinical measures and the first peak vertical force and the second peak vertical force symmetry

From the present results, there were significant relationships of the first peak vertical force symmetry and tone of the muscles in hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors in the comfortable gait speed as shown in Table 4.5. Increasing of asymmetry of contributing first peak force between the affected and the un-affected sides was corresponded to the increasing of these muscle tones. There were several studies supported that the alteration in muscle tone influenced the gait performance by their abnormal force generating during different gait events of walking, especially the push off event (11, 128, 190).

In the present study, most stroke subjects (22 from 30 stroke subjects) had greater amount of the first peak vertical force which was occurred during the early stance phase of gait in the affected than the un-affected side only at the comfortable gait speed. The first peak vertical force occurred during the early stance phase of gait to maintain body center of mass over the supporting limb. However, greater first peak vertical force in the affected side than the un-affected probably happened because the affected foot could not decelerate and transfer weight over the stance phase. No relationship in the fast speed may be came from the diverse strategies used to generate the first peak vertical force in the patients with stroke when speed of waking was increased as observed in the reduction of number of the stroke subjects who had more first peak vertical force in the affected side (20 from 30 stroke subjects) when comparing to the comfortable gait speed as stated in the aforementioned. The great variability of force contributing pattern which existed in the present study may play a part for the detecting this relationship as reported in the previous studies (195, 196).

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Moreover, there were no significant relationships of the first peak vertical force symmetry and the BBS and FMA at both comfortable and fast gait speeds. It is indicated that postural balance and motor function may not play an important function to control symmetry during the early stance phase of gait as explaining by generating the first peak vertical force symmetry.

It was found that the number of the stroke subjects who expressed the asymmetrical pattern of the second peak vertical force between the affected and the un-affected sides was varied. It was not consistent, according to the data of some patients showed the higher second peak vertical force in the un-affected side than the affected side, while some patients showed vice versa.

However, stroke subjects showed more second peak vertical force on the un-affected side than the affected side at both comfortable and fast gait speeds (18 and 20 from 30 stroke subjects, respectively) as exhibited in Table 4.4. Only the tone of hip extensors which was found significantly related with the second peak vertical force symmetry at the fast gait speed (r_s = -0.449, p<0.05). The negative relationship indicated that the asymmetry of the second peak vertical force was increased when the tone of hip extensors of the affected leg decreased. Reduction in this muscle tone may inhibit the construction of the second peak vertical force during walking. Normally, hip extensor muscle is required for contributing the force to push the body forward since the preswing. From the results, increasing in hip extensors muscle tone assist the symmetry of the generating second peak vertical force during the fast gait speed. However, the relationship was not occurred in the comfortable gait speed. It may imply that the overactivity of the hip extensor muscles may not helpful in all situation of walking.

Moreover, there were no significant relationships of the second peak vertical force symmetry and the BBS and FMA at both comfortable and fast gait speeds. It indicated that postural balance and motor function may not play an important role to generating the second peak vertical force during the late stance.

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- Correlations between clinical measures and the single support symmetry

Positive relationships were found between the symmetry of the single support time and the tone of hip extensors, knee extensors, ankle plantarflexors, and ankle invertors at the fast gait speed. These muscles play an important role in gait during the period of single leg stand on the ground. At the fast gait speed, asymmetrical single stance time increased when these muscle tones increased. Only the ankle plantarflexors tone was reported to associate with the single support time symmetry (49). The spasticity of the affected ankle plantarflexors was suggested to be the primary independent determinant of the temporal asymmetry in both comfortable and fast gait speed conditions, followed by the motor function and sensation of the affected lower extremity (49). The spasticity of the affected ankle plantarflexors to temporal asymmetry in hemiparetic gait was investigated by Hesse et al in 1995 (188). The results showed that a combination of electrical stimulation and botulinum toxin injection significantly reduced the spasticity of the affected ankle plantarflexors in patients with stroke and improved the single support time symmetry between the two lower extremities.

In the present study, the significant relationships were found in the single support time symmetry and the ankle invertors tone at the comfortable gait speed. It can be stated that the ankle invertor tone plays a role in the natural speed of walking in patients with stroke to control the time when baring their weight on the affected leg. In both the comfortable and fast gait speeds, most stroke subjects tend to bare their weight on the un-affected side more than the affected side (27 from 30 stroke subjects). It is well known that the spasticity in patients with stroke will increase when the patients pay more attention during a challenging task, for instance, the difficult, complicated, and very fast movement. At the fast gait speed, the increase in tone of the hip extensors, knee extensors, ankle plantarflexors, and especially, the ankle invertors which was over the normal level may impede the weight bearing function on the affected side. Therefore, the single leg stance time consumed by the affected leg was reduced and less than that of the un-affected side.

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Furthermore, the present study found the relationship of the single support time symmetry and the motor function as detected by the FMA at both comfortable and fast gait speeds (r_p = -0.662 and r_p = -0.648, respectively). With the negative relationships, it is indicated that the asymmetry of time consumed in the single leg stance between the affected and the un-affected sides will increase when the motor function of the stroke reduces. In other aspect, motor function influences to maintain time used in the weight bearing task of two legs when walking. Similar to the study of Brandstater et al in 1983 (33), relationship of the motor recovery stage of the affected lower extremity and single support time symmetry in patients with hemiparesis is high.

- **Correlations between clinical measures and the step time symmetry**

It was found that the tone of hip extensors (r_s = 0.391), knee extensors (r_s = 0.454), and ankle invertors (r_s = 0.389) were related to the step time symmetry with the positive direction at the comfortable gait speed. Thus, when walking at the comfortable gait speed, the increase in these muscle tones will increase asymmetry of time consumed during step between the affected and the un-affected sides. Most stroke subjects consumed the step time in the affected side longer than the un-affected side at both comfortable and fast gait speeds (27 from 30 stroke subjects and 28 from 30 stroke subjects, respectively). The increase in time to step indicates the increase in difficulty in stepping forward during walking. The increase in these muscle tones may limit normal step function in the stroke. The difficulty in releasing or eccentric contraction of the hip extensors beginning prior to the swing period can happen if the muscle still has spasticity. Therefore, time to step will be longer as shown with prolonged electromyography activity. Prolonged activity of biceps femoris and rectus femoris during the single support phase was stated as the abnormal prominent feature in patients with stroke (190). Knee extensors is the other muscle which play a critical role to step forward. Prolonged activity of quadriceps muscle was also suggested to be the abnormal common feature of neuromuscular co-ordination in hemiparetic gait (190). Increasing of the quadriceps tone can impedes the appropriate concentric contraction during the swing period. In the present study, relationship of the

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knee extensor tone to the step time symmetry was also showed at the fast gait speed (r_s = 0.425). It is possible that when the task is difficult, such as increasing speed, the spasticity of knee extensors may increase and intervene forward stepping than the other muscles. For the ankle invertors, this muscle influences foot clearing from the floor during the swing phase. In stance phase, limit the movement in the ankle inversion can affect to the normal pattern of foot contact. Furthermore, in the late stance, the increase in the ankle invertor tone may reduce force pushing the body forward and leading to the longer step time (95, 197).

In addition, there were negative relationships of the step time symmetry and the motor function at both comfortable and fast gait speeds (r_p = -0.556 and r_p = -0.447, respectively). It is implied that improve in motor function of the affected side will develop the symmetry of time to step between the affected and the un-affected sides. Little is known about the relationship of step time and the motor function in the stroke. Most published data investigated in the temporo-spatial variables and reported with the single and double support times and the step length. However, it is interesting to study the relationship of temporal variable as the step time and clinical measures because the different function in stroke gait.

- Correlations between clinical measures and the stance time symmetry

For the stance time, the present result demonstrated consistency pattern between the affected and the un-affected sides. All stroke subjects showed greater stance time on the un-affected side than the affected side at both comfortable and fast gait speeds. The relationship between the stance time symmetry and the clinical measures was demonstrated in the MAS and FMA. At both comfortable and fast gait speeds, tone of knee extensors (r_s = 0.451 and r_s = 0.397, respectively) and ankle invertors (r_s = 0.426 and r_s = 0.451, respectively) were related with the stance time symmetry in positive direction. It is indicated that when the tone of these muscles increases, the asymmetry of stance time also increases. Increasing of knee extensors spasticity is the factor that induces the knee to hyperextend in the stroke (95). Besides to knee extensors, the ankle invertor tone was also related to the symmetry of stance

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time. Improper foot placement as the dynamic equines deformity of the ankle from calf muscle spasticity can impede toe clearance during the swing phase of gait causing the patient to fall (190). Inappropriate activity in the intrinsic muscles of the foot and long toe flexors may cause painful toe flexion and difficulty walking. Normal weight bearing over the foot necessitate the proper muscle control and the appropriate function of the knee and foot.

Furthermore, there were negative relationships of the stance time symmetry and the FMA at both comfortable and fast gait speeds (r_p = -0.620 and r_p = -0.656, respectively). It is indicated that the asymmetry of time consumed in the stance phase of gait between the affected and the un-affected side will increase when the motor function of the stroke reduces. There was reported that the stance time symmetry was related to the gait speed. It is well known that the gait speed is a good predictor of walking during the period of recovery time in the stroke (18, 119, 184, 185). Therefore, the improvement of the lower extremity motor function may assist the symmetry of stance time when walking in patients with stroke.

- Correlations between clinical measures and the swing time symmetry

Another consistent variable existing between the affected and the un-affected side performance in the stroke was the swing time. At both comfortable and fast gait speeds, it was found that the stroke had greater swing time in the affected side than the un-affected side (all 30 stroke subjects). From the present results, there were significant relationships of all muscle tones (hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors) and the swing time symmetry at both comfortable and fast gait speeds. It may indicate that these muscles play a role during the swing phase. The increase in these muscle tones increases the asymmetry of swing time between the affected and the un-affected sides. In the stroke, longer swing time of the affected side comparing to the un-affected side was observed when these muscle tones increase. Extended swing time of the affected side may result from the difficulty to release or relax the muscles as expressed in the extensor synergy than the isolated functions (107). Inability to isolate single joint

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movement always expresses in patients with stroke (107). Another possible reason of prolonged affected swing time may relate to shorten affected stance and also relate to the contra-lateral un-affected side.

Furthermore, there were negative relationships of the swing time symmetry and the FMA at both comfortable and fast gait speeds (r_p = -0.676 and r_p = -0.682, respectively). The present result was similar to the previous study (188), which was revealed that the motor status of the affected lower extremities of patients with stroke correlated negatively with the swing phase of the affected lower extremity. Therefore, it is indicated that the asymmetry of time consumed in the swing phase of gait between the affected and the un-affected side increases when the motor function of the stroke reduces. Because the FMA emphasizes the assessment of the strength of the knee flexors and ankle dorsiflexors, rather than the extensors, similar to the swing phase function which is required the flexion activity to lift the leg. It explained why the FMA was related to the performance of the swing movement during gait in stroke patients (188). Furthermore, there was report that the increase in swing time asymmetry was related to the compensatory strategies, for instance, the hip hiking and circumduction and led to increased mechanical energetic cost in the stroke when walking (113). Hence, in obtaining more symmetry of the swing time, lower extremity function is the other factor which suggested being concerned.

In conclusion, asymmetrical function occurred in patients with stroke at various phases and events of gait and in different conditions of gait speed. The relationships demonstrated in the present study indicated that to improve gait symmetry, there were several parts to determine and remedy individuals with stroke. One should pay more consideration to the abnormal lower extremity muscle tones and the motor function for solving abnormal asymmetrical gait characteristics. Although there was no relationship of any symmetrical gait variables and the BBS, the postural balance is important for gait improvement because balance performance is a factor stated to be critical for dynamic movement, such as gait (76, 120, 198).

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5.3 Comparisons of Gait Biomechanic Characteristics between the Control and the Stroke

5.3.1 Temporo-spatial

Comparisons between the control and the stroke, there were significant differences in cadence, double support time, step width, stride length, stride time, and gait speed at both comfortable and fast gait speeds as shown in Table 4.8. Similar to several previous studies (16, 18, 20, 31, 33, 43, 73, 115), the stroke showed a decrease in cadence, stride length, and gait speed and demonstrated an increase in the double support time, step width, and stride time when comparing to the control. Decrease in number of steps and stride length of the stroke is corresponding to the gait speed reduction (96). Nevertheless, gait speed has been consistently reported to be one of the variable that differentiates walking characteristics between the stroke compared with the age-matched healthy individuals (16, 18). Thus, it should be noted that some abnormal existing in the stroke caused by the different gait speed inherently.

In the stroke who lack proper postural balance control during movement as walking, they may compensate by increasing the time of both feet on the ground and walking with greater step width (124). Total time used over the gait cycle as reported with the stride time was longer in the stroke when compared to those of the control.

Comparisons of the single support time, step length, and step time between the control and the un-affected, the control and the affected sides, and the un-affected and the affected sides, at both comfortable and fast gait speeds were investigated. There were significant differences in all testing except for the single support time between the control and the affected side of the stroke. For the single support time, the un-affected side showed longer single support time when comparing to the control and the affected side. It may be the compensatory function of the un-affected side to obtain more postural balance and to gain more stability during the stance phase of gait. In addition, the proportion of time spent in the stance versus the swing is also altered both on the affected and the un-affected sides, when compared to

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healthy subjects walking, similar to those of the previous studies (28, 31, 33, 115). In addition, the proportion of time spent in stance phase tends to be longer on both the affected and the un-affected sides (113).

Decrease in step length of both the un-affected and the affected sides comparing to the control were shown in the present results. Shorter step length of the affected side may result from the impairment on that side such as the increased tone and poor motor function. The shorter step length of the un-affected side may result from an inability or unfully ability to generate normal function of the affected side. The movement of the un-affected side during walking requires stable control of the affected stance. During step, stroke subjects have difficulty in both the distance and time controls.

In the present study, it was found that the un-affected and the affected sides showed longer step time than the control did and the affected side demonstrated longer step time than the un-affected did. For the longer step time in the affected side comparing to the control, it may be due to the inaccurate in the swing performance of the affected side. During swinging the un-affected side in the swing phase of gait, the affected side needs to bear whole body weight. Having an increase in muscle tone and a poor motor control, the affected side is possible take much time before the un-affected side is initiated to swing. Furthermore, the affected side cannot completely perform function in weight bearing. Hence, the affected side is shortly swung. Similar to the previous study (199), step length asymmetry in the stroke is discovered to relate with the propulsive force generation during walking. Stroke subjects generating least affected propulsion walk with relatively longer step. This suggested that one of the mechanisms for the longer affected step may be the relatively greater compensatory un-affected leg propulsion (199). Therefore, in the un-affected side, the less step length and the longer step time were shown. For the longer step time in the affected side comparing to the control and the un-affected side, it may be from the increase in muscle tone in the affected side causing a difficulty in movement and motor control. Literatures supported that the increase in tone or existence of spasticity can trigger

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inappropriate muscle activity causing the movement deficits and unintentional movements (62, 95, 200, 201).

5.3.2 Kinematics

5.3.2.1 Angular displacement (degrees)

The present results illustrated the deviated gait displacement pattern in both the affected and the un-affected sides were observed in the joint angular displacements. Aberrant movement patterns of the stroke gait occurred in the sagittal, frontal, and transverse planes of movement. Not only the affected side but also the un-affected side showed the deviated movement patterns from the normal. This aberrant gait pattern in the stroke may result from compensatory movements in order to complete the tasks of walking. In addition, delayed initiation of motion was found in the angular displacements of the hip, knee, and ankle similar to the previous report (107). The angular displacements of the un-affected side showed more closely to those of the control rather than the affected side. Obviously, distinction of displacements can be detected in the sagittal plane movement which was reported with the joint excursion reduction in the stroke. The joint angular displacements in the frontal and horizontal planes observed in the stroke were very few.

There was reported that the slower speed in the hemiparetic gait associated with smaller joint excursions in the lower limbs (202). Thus, it should be noted that the slow speed can cause the decrease in joint peak angular velocities during walking in the patients (21, 31, 133). Nevertheless, it is not entirely clear as to which the kinematic deviation remains independence on gait speed. Few studies compared speed-matched lower limb kinematics between the stroke and the control. Results demonstrated significant differences of kinematics in the stroke comparing to the control such as less hip extension of the affected and the un-affected sides at the TO, reduced knee flexion and ankle dorsiflexion of the affected side during the swing phase, and larger lateral foot displacement of the affected and the un-affected sides (23, 112, 113). It, thus, appears that some kinematic deviation in the stroke remain independent on, or not entirely attributable to a slower gait speed. The present study interested was to investigate the walking characteristics in natural condition. Thus, the

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walking speed was not controlled. The differences in the angular displacement of the hip, knee, and ankle during walking in the stroke were presented the natural walking characteristics of the stroke in two conditions: comfortable and fast gait speeds.

From the present results, significant differences of angular displacements of hip, knee, and ankle in the sagittal, frontal, and transverse planes between the control, the un-affected, and the affected sides and between the un-affected and the affected sides at both comfortable and fast gait speeds were demonstrated as shown in Table 4.12-4.13.

For the un-affected side at the comfortable gait speed, at the IC, the un-affected hip showed more adduction than the control. However, only the un-affected hip showed significant difference from the normal, but not from the affected hip. Because the weakness of the affected lower extremity muscles, the stroke tend to lean and bear their weight on the stronger limb, the un-affected limb (52).

Great weight shifting of the upper body on the un-affected limb in the stance phase of gait caused the position of the un-affected hip tend to adduct. At the MS, the un-affected hip showed less abduction and more external rotation when compared to the control. Similar to the previous studies (30, 203), the un-affected and the affected hips showed external rotated instead of slight internal rotate as the normal expressed. External rotation of the un-affected and the affected sides of the stroke may result from trying to increase the base of support during the MS event. At the TO, the un-affected hip demonstrated slight flexion while the control demonstrated small degree of hip extension (197). It may be caused by very short step length of the affected side. Thus, the motion of the un-affected hip in extension did not happen. For the affected side at the comfortable gait speed, at the IC, the affected hip showed less flexion and more abduction than the un-affected hip. Weakness of hip flexion of the affected side and other causes of impairment such as an increase in tone of lower extremity muscles impede the hip flexion during the IC. However more abduction of the affected hip when compared to the un-affected hip was not significantly different. At the MS, the affected hip showed less flexion and more abduction than the un-

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affected hip. Less degree of hip flexion in the affected side was come from poor motor control and weakness of the hip flexors. More hip abduction of the affected than the un-affected is possible resulted from uneven weight bearing as stated in the aforementioned. In addition, it may result from the uncontrollable movement of the affected leg to advance the leg in forward direction causing from weakness of the hip, knee and ankle flexor muscles. Inappropriate swinging and placement the affected leg was the additional factor leading to deviated degree of motion of lower extremity joints in stance. At the TO, the affected hip showed less adduction than the normal and the un-affected hip. This circumduction gait is usually presented and reported to be the common abnormal characteristic in the stroke (21, 35).

At the comfortable gait speed, the un-affected knee showed more flexion than the control at the IC. It corresponded to the very short step length of the un-affected side which happened in the stroke as shown in Table 4.9. Short step length of the un-affected may enhance more flexion of the un-affected passively. The knee movement of the un-affected side was similar to that of the control in the MS. However, at the TO, the un-affected knee showed more flexion than the control knee. At the time of TO in the un-affected side, the affected side has to prepare for acceptance the body weight. However, it is very hard for the stroke to transfer their weight on the affected side due to muscular weakness, decrease in motor function and postural balance, so more knee flexion of the un-affected can occur if the patients still bear their weight on the un-affected side. For the affected knee at the IC, the affected knee less flexed than the un-affected knee. In addition, the affected knee showed abduction whereas the control and the un-affected knee showed adduction. In the transverse plane, the affected knee showed more external rotation than the control. Abnormal abduction occurs with external rotation of the affected knee caused by the improper foot placement. Weakness of the affected side is another possible cause of this movement. At the MS, the affected knee flexed less than the control and the un-affected. In general, the knee should be slight flexion at the MS for shock absorbing function in reducing the energy consumption during walking. The difficulty to control knee to flex in the MS event may be resulted from the hypertone of knee extensors or weakness of the knee muscles. In the frontal plane, the present results also revealed

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that the affected knee had abduction in stead of minimal adduction during the MS. The abduction of the affected knee occurred continuing from the early event. It is implied that the stroke had the difficulty to transfer the weight to the affected limb, thus, leading to abnormal abducted knee occurred in this side. At the TO, the affected knee flexed less than the control and the un-affected side. The reduction of the affected knee to flex may influence by the extensor synergy and lack of knee flexion control (107).

The un-affected ankle showed similar angular displacement to the control at the IC. However, the un-affected ankle showed less abduction at the MS and less plantarflexion at the TO when compared to the control. Less un-affected ankle abduction can be observed in most stroke who are usually unable to control the affected leg. The un-affected side is always used as the leading leg to progress body move forward and the stability part to balance the upper body when walking. Thus, the affected ankle tends to place in the position to move in forward direction. For less plantarflexion of the un-affected ankle may corresponding to the short step length and impaired postural balance. Insufficient hip extension may limit the degree of ankle motion and lead to less propulsive force exerted during the terminal stance. For the affected ankle, loss of normal heel strike in the patients with stroke was shown as presented with the minimal ankle plantarflexion (21, 26) instead of dorsiflexion at the IC event. However, this difference was not significant between the affected and the control and the un-affected side. There was less affected ankle dorsiflexion at the MS when compared to the control and the un-affected. It may be caused by the spasticity of the ankle plantarflexors, muscle weakness, abnormal muscle activity, inadequate muscle co-activation, sensory deficits, and noncontractile soft-tissue tightness (21, 25, 54, 64, 192). In addition, the spasticity of the knee extensors may be the factor that limit the shank to move rotated forward and not allowed the ankle to dorsiflex (23, 30). Interestingly, at the TO, the affected ankle showed dorsiflexion, whereas the control and the un-affected knee showed plantarflexion. Loss of foot and ankle flexibility, poor motor control, and abnormal tone in the ankle and intrinsic muscles may impede the ankle plantarflexors to generate the propulsive force and propel the body forward.

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At the fast gait speed, significant differences of the angular displacements of hip, knee, and ankle between the control and the un-affected side, between the control and the affected side, and between the un-affected and the affected sides were similar to those of the comfortable gait speed. It is indicated that the stroke had the same characteristics of walking at both the comfortable and fast gait speeds. However, there were some additional differences in angular displacement at the fast gait speed, in the sagittal and the transverse planes, but not in the frontal plane. In the sagittal plane, the present results showed the differences in the hip and the ankle between the affected side compared to the control and the un-affected side. The affected hip showed less extension than the control at the TO. Less extension in the affected hip may result from the stroke trying to keep center of mass close to the body as much as possible. It is the compensatory function for the affected side to conserve energy and use minimal muscle control when the limb is close to the body. Furthermore, the affected ankle showed less dorsiflexion than the control and the un-affected side during the IC. An ability to control the ankle movement during the complicated task such as walking is extremely hard for the stroke, providing the normal ankle control sometimes necessitates the ankle foot orthoses (23, 204, 205). For the transverse plane, the un-affected ankle showed less external rotation than the control at the MS. Less external rotation of the un-affected ankle may act as the compensatory mechanism to advance this leg to progress forward.

5.3.2.2 Angular velocity (degrees/s)

Joint angular velocity during walking has rarely been examined in patients with stroke, but more often identified in the cerebral palsy condition (206, 207). Velocity components of gait kinematics are suggested as a valuable source of information for evaluating walking dysfunction. Joint velocity profiles of patients with neuromuscular impairment are markedly different than normal subjects. In cooperating joint angular velocity data into motion studies of gait can potentially improve the ability to categorize subjects and quantify rehabilitation progress (207).

Increase in hip and knee flexion velocity during the initial swing were significantly presented in the un-affected side when compared to the control and

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the affected side at both comfortable and fast gait speeds. In contrast, the un-affected side showed less ankle plantarflexion during the initial swing when compared to the control. The increase in hip and knee flexion angular velocities during the initial swing of the un-affected side is possibly resulted from the unfully weight bearing on the affected side. Inability to support the whole weight on the affected side leads to compensatory movement of the un-affected side. Thus, fast flexion movements of the hip and knee joints occur in the early swing phase of gait. However, the decrease in the ankle plantarflexion velocity during the initial swing of the un-affected side may be due to the difficulty to control postural balance and movement in the early period of transferring body weight to the affected side. For the affected side, similar to the previous study (27), the present study showed significant decrease in angular velocity at the initial and terminal swing of the hip, knee, and ankle joints of the affected side when comparing to the control and the un-affected side at both comfortable and fast gait speeds. It may be from the fact that several impairments such as loss of postural balance, poor motor function, and deviated muscle tone occur in the affected side. An explanation of the reduced joint angular velocity and abnormal muscle tone relationship is involved the velocity-dependent hypertonicity in antagonistic or co-spastic muscles that generate deceleration forces, thereby limiting the magnitude of the joint angular velocity. The reduced joint angular velocity may also reflect the stiffness of the fibrous components of the muscle-tendon unit, such as the muscle sheath and tendon. In other words, limited joint angular velocity may be the result of reduced muscle-tendon extensibility (206). Additionally, it should be noted that the decrease in swing velocity of the affected side in the stroke were distinctly in the ankle during the initial swing (A1) and midswing (A2).

Ankle plantarflexor muscles are reported to be important for gait speed and symmetry both in the normal and the stroke (64, 137, 170) because the force of ankle plantarflexors is critical for propelling body forward during push off phase from the late stance (40% of gait cycle) to the end of TO (60% of gait cycle) in normal (38). The reduction of ankle plantarflexors functions during push off phase of gait in the stroke compensated by increasing the velocity of other parts (38). Additional support found that some subjects with stroke compensated the weakness of

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ankle plantarflexors by pulling off the limb with their hip flexors (38). Moreover, the recovery of the distal part like the ankle was hard and pertained much of time. Thus, the affected ankle seems decrease the angular velocity more than the other joints.

In conclusion, angular velocity can provide a more clearly picture of gait characteristic of patients with stroke by compare the differences of the angular velocity between the un-affected and the affected sides of the stroke and between the control compare to both sides of the stroke. Further study should investigate more information associating the cause of compensatory adaptation of increased angular velocity in specific joints such as the hip and knee of the un-affected side in patients with stroke.

5.3.3 Ground reaction forces (%BW)

GRFs characteristics of the stroke displayed very jerky pattern, there was differ to the continuity and smooth pattern exhibited by the control. A patient with hemiplegic stroke may lose the typical heel-strike and push-off mechanisms, altering GRF pattern from the vertical bimodal to a pathologic shape were demonstrated in the present study. Most of the stroke subjects (19 from 30 subjects) exhibited initial medial force instead of the lateral force as normal presents.

Up to date, the variability have been studied in many conditions of normal and neurological problems (37, 195, 208). No reports regarding to the comparisons of the magnitude of the GRFs in patients with stroke and normal. Consequently, the differences in GRFs between the control and both sides of the stroke and between sides of the stroke were available in the present study. The present study compared seven GRFs, composed of the forces in the medio-lateral direction (X1, X2, X3), antero-posterior direction (Y1, Y2) and vertical direction (Z1, Z2). In the control group, the shape and magnitude of GRFs presented in this study are in agreement with and similar to previous published findings (97, 196, 197). Comparison of GRFs demonstrated significant differences between the control and the affected, the control and the un-affected, and the un-affected and the affected sides of the stroke.

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For the medio-lateral force, there was no significant difference between the control and the un-affected side. However, the affected side had significant lesser lateral force and greater the first and second medial forces than the control and the un-affected side at both the comfortable and fast gait speeds. Less lateral force and great medial force in the affected side may be come from the inappropriate foot contact. Gaviria et al in 1996 (209) noticed that a tendency for first heel contact was disappeared on the affected side in hemiplegic patients. Hemiplegic patients with strong extensor synergies often show equinus foot postures in the affected side throughout the stance phase (33). Additionally, the ankle plantarflexors and invertors spasticity which were presented in the stroke populations of the present study may relate to the abnormal contributing force in the medio-lateral directions.

For the antero-posterior force, there was reported that the un-affected and the affected sides had significant less braking and propulsive forces than the control at both comfortable and fast gait speeds. The reduced affected propulsion may be the result of exaggerated ankle, knee, or hip joints acting to offload the leg. More flexion of hip and ankle may lead to inappropriate hip extension during push off. The insufficient hip extension force leading to less affected propulsion in eventually (210). Less braking and propulsive forces of the un-affected and the affected legs can lead to slow gait speed in stroke as present in the Table 4.8. However, the comparisons of antero-posterior force between the un-affected and the affected showed that the affected had less propulsive force than the un-affected side but not for the braking force. No difference of the braking force between the affected and the un-affected sides may result from the uncontrollable foot during the early stance phase of gait. Therefore, the affected foot may attack to the floor abruptly and making rather great force. Inappropriate shear forces production may lead to loss of postural balance control and finally fall in the stroke populations when walking (96, 193).

For the vertical force, the un-affected side had less first and second vertical forces than the control at both the comfortable and fast gait speeds. The less vertical force is directly corresponded to the slow velocity of walking in patients with stroke and the difficulty to transfer and maintain the body weight over the foot during

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the stance phase of gait. Comparisons of the vertical force between the affected and the control showed significant less first peak force at the fast gait speed and less second peak force at both comfortable and fast gait speeds. During the comfortable gait speed, the stroke may walk with the difficulty to control the foot over the floor during the early stance phase of gait. Thus, the first peak vertical force did not differ from the control though they walked with slower gait speed. In contrast to the fast gait speed, this situation may induce spasticity in the patients and used more effort to release it. Comparisons of the vertical force between the un-affected and the affected showed the greater first peak vertical force at the comfortable speed and the less second peak vertical force at the fast speed of the affected than the un-affected side. In normal, the first and second peak vertical forces exist during the early and late stance phase of gait. The first and the second peak vertical forces used for maintaining the body weight during walking when the leg moves as leading and trailing limb respectively. There was no change in the force contributing by the affected leg at both the comfortable and fast gait speeds. In contrast, the control and the un-affected sides demonstrated the increase in the first and second peak vertical forces.

As presented in the results, abnormal characteristic of both the affected and the un-affected GRFs were observed in patients with stroke. Abnormal characteristics which were found in the stroke gait should be noted in both the affected and un-affected limbs, suggesting that rehabilitation programs should be implemented not only in the affected but also in the un-affected side.

5.4 Clinical Implication, Limitation, and Further Study

5.4.1 Clinical Implication

In stroke patients, gait performances in terms of speed and symmetry were affected by the changes of clinical measures as illustrated with the relationships of clinical measures and gait performances in the present study. In order to develop the walking speed and appearance, excessive lower extremity muscle tones, affected postural balance, and lower extremity motor function should be remedied.

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In the comparisons section, the present study exhibited the valuable information of the differences in gait biomechanics between the affected, the un-affected, and the control. With testing both the affected and the un-affected sides simultaneously, adaptive compensatory mechanism can be seen as reported with the alterations of several gait biomechanic variables. Besides the deviations of the temporo-spatials and joint angular displacements which frequently stated in previously, the present results further give more deviated gait characters as observed in the joint angular velocities and GRFs. Abnormal walking characteristics can be demonstrated by the significant differences of the temporo-spatial, kinematic and kinetic variables appearing in the affected and the un-affected sides of the stroke from the control.

Beyond speed of walking was changed, the present study found common deviation patterns happening in both sides of the stroke when compare to the control. Significant differences were in the same trends at both comfortable and fast gait speeds. It indicated that patients with stroke tend to use the same mechanism to control their movement during walking even speed of walking was changed. Another possible reason may result from their poor adaptability to perform the function during environmental context differences.

5.4.2 Limitation

According to limitation of equipment, there was only one force plate embedded in the walkway of the Motion laboratory, gait symmetry between the affected and the un-affected limbs in the present study was derived from the data of non-consecutive steps or different trials. However, to decrease this effect, the data of the present study were from the average of three walking trials and only on the middle part of walk way. The results in the present study indicated that patients with stroke learned an individual gait pattern adaptation to specific circumstances as expressed with different pattern of biomechanic variables during walking. It is very difficult to recruit them into homogenous group. However, it does not mean that this approach cannot be applied to determine the degree of gait deficiency. Hence, gait characteristic

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of patients with stroke can be relied on the results of the present study only in part, specifically upon similar criteria and methodology which existing in the study.

In addition, the present study determined only on the outcome of gait performance as expressed with the temporo-spatials, joint angular displacements and velocities, and ground reaction forces. Causal factor of those deviated walking characteristics should be quantified together with electromyography researches.

5.4.3 Further Study

The mechanics of human gait involve synchronization of the skeletal, neurological, and muscular system of the human body. This complexity of the interaction of the various components of human gait has been researched and documented for many years. However, some facet of gait disturbance is still questionable in stroke and requires further researches to explain and find out causes and effects. Wider application of the results based on basic and advance knowledge of the clinical practice is great and ongoing challenge. In clinic, study of various clinical variables should be established for acquiring more knowledge about the most sensitive outcome measure in each motor recovery stage of the patients. The specific muscle stereotype pattern in patients with stroke should be quantified in order to understand more about the function and assist in clinical intervention program individually. In laboratory, there was necessary to research the kinematic and kinetic data in combination with the muscle activity during gait. Stance as well as swing phase mechanics are also play critical roles in providing the stabilizing and moving cues for walking function in respective, thus, it should be investigated in the swing mechanics for an explaining of moving performance. In addition, effect of other body parts such as the trunk or arm segments to the walking ability are interesting. Finally, the study of linking the clinical and laboratory parameters was still rare. The most difficult aspect was in the interpretation of this linking data in order to send the information from one to another.

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CHAPTER VI
CONCLUSION

The present study investigated, firstly, the relationships between clinical measures (lower extremity muscle tone, postural balance, and lower extremity motor function) and gait performances (gait speed and symmetry) in the stroke. Secondly, gait biomechanic characteristics at both gait speeds were compared among the control, the un-affected, and the affected legs of the stroke. Each of thirty control and stroke subjects participated in the study. Conclusions were stated in the following;

1. Relationships between clinical measures and gait performances

Negative and positive relationships were found between gait performances and lower extremity muscle tone and motor function, respectively. It implied that excessive muscle tone impeded gait speed and symmetry, while the lower extremity motor function assist walking performances of the stroke instead. Only the affected postural balance was related with the gait speed, implied that better postural balance on the affected side was, the better gait speed was. Thus, the present study suggested that muscle tone, lower extremity motor function, and postural balance on the affected side were the important elements influencing gait performances. For clinical application, physical therapists should reduce muscle tone of hip adductors, hip extensors, knee extensors, ankle plantarflexors, and ankle invertors and should increase motor function of lower extremity and postural balance specifically on the affected side for gait improvement.

2. Comparisons of gait biomechanics among the affected, the un-affected, and the control

Aberrant gait characteristic of both the affected and the un-affected sides of the stroke can be distinguished from the control and can be observed with the increase or decrease in several gait variables. Those deviations appearing in the

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affected and the un-affected sides may indicate an inability to control movement and to perform function as well as act the compensatory movement in the stroke patients.

2.1 The affected side of the stroke

The affected side of the stroke was expected to express with the decrease in gait biomechanic data caused by several impairment existing in this side, however, some parameter expressed increasingly instead. Inability to control leg movement especially in the affected leg resulted in less ranges of joint motion which were exhibited in three planes of motion and explicitly existed in the frontal and transverse planes. For the temporo-spatials, the affected side as well as the un-affected side expressed with decrease in stride length, and gait speed when compared to the control. The affected side had significantly decreased in the hip (H), knee (K1 and K2) and ankle 9A1 and A2) angular velocities during the swing phase of gait when compared to the control and the un-affected side of the stroke. Uncontrollable the foot segment and abnormal foot posture in the stroke subjects may relate the deviations of the ground reaction forces contribution in the affected leg. The results showed that the affected had significantly increased of force in the first peak medial (X2) and second peak medial (X3) forces at both gait speeds and decrease in the first peak lateral (X1), braking peak (Y1), propulsion peak (Y2), and second peak vertical (Z2) forces at both gait speeds, and the first peak vertical (Z1) force at fast gait speed when compared to the control. Increasing of gait variables data in both sides of the stroke also were found. Regarding with an inability to control postural balance during walking in the stroke can be observed with a significantly increase in the double support time, step width, and stride time of the affected and the un-affected sides of the stroke when compared to the control.

2.2 The un-affected side of the stroke

For the un-affected side of the stroke, was principally used as the moving and stabilizing leg and assist the whole body move during walking. Thus, increasing value of the several variables can be seen in the un-affected side as the compensatory mechanism for assisting the affected side to move. Increasing of the joint angular velocity was exhibited in the un-affected side in the hip (H) and knee

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(K1) velocities during initial swing when compared to the control and the affected side of the stroke. However, the un-affected ankle velocity during the initial swing (A1) was decreased when compared to the control for maintain postural balance in preparing the affected swinging function. According to the slow walking velocity, the un-affected side had significantly decreased of forces in the braking peak (Y1), propulsion peak (Y2), first peak vertical (Z1), and second peak vertical (Z2) forces at both gait speeds when compared to the control. These abnormal gait characteristic of the un-affected side probably resulted from the alteration after patients had stroke inherently as presented with the decrease in several data. Likewise, the increase in the gait mechanic control may be act as the compensating function for the reduction of regulating the movement in the affected side.

3. Speed-related the stroke gait biomechanics

Almost gait kinematic and kinetic variables detecting in the present study, demonstrated significant differences in the same manner at both the comfortable and fast gait speeds. It may indicate that the stroke used the similar mechanisms in walking during the different environmental context. In another aspect, it may be due to inadaptability for performing more complicated function when walking faster of the stroke patients.

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APPENDIX

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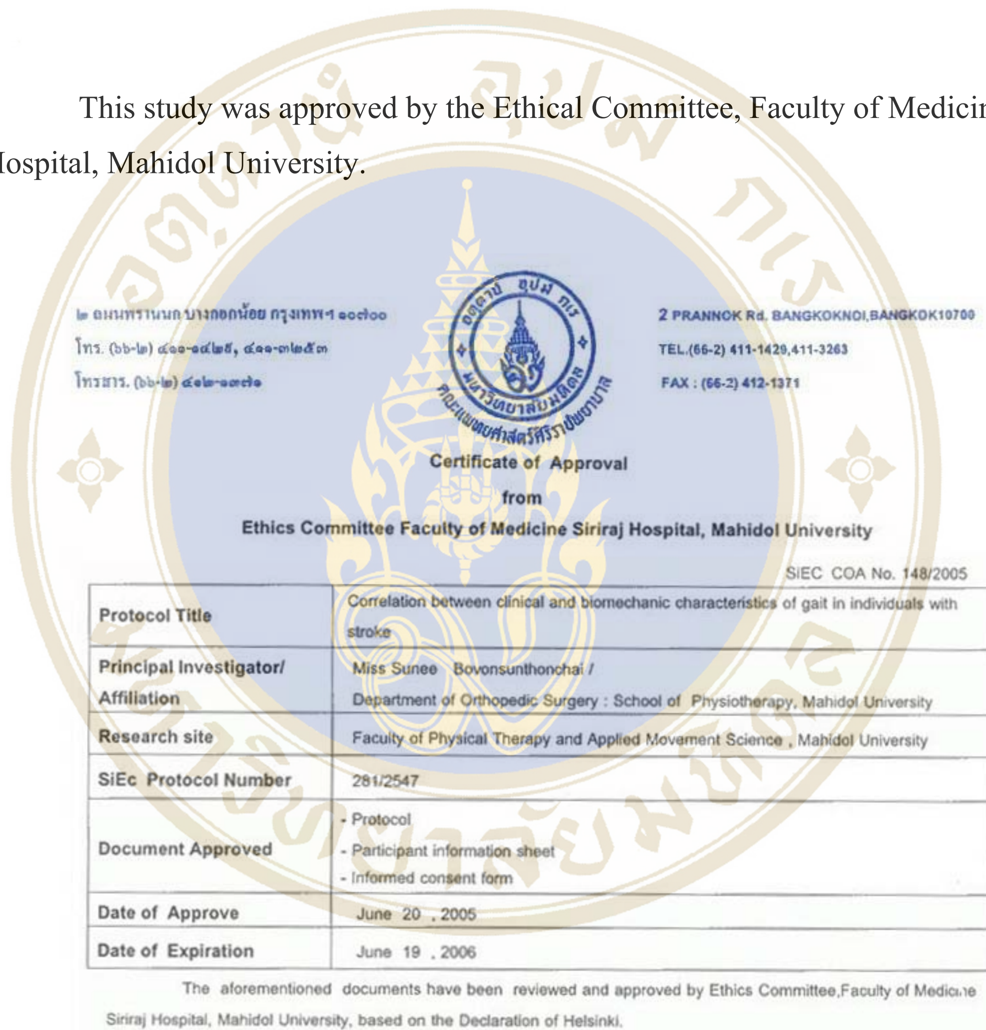
APPENDIX A
THE ETHICAL COMMITTEE ON RESEARCH INVOLVING HUMAN SUBJECT

This study was approved by the Ethical Committee, Faculty of Medicine Siriraj Hospital, Mahidol University.



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Certificate of Approval
from
Ethics Committee Faculty of Medicine Siriraj Hospital, Mahidol University

SIEC COA No. 148/2005

Protocol Title	Correlation between clinical and biomechanic characteristics of gait in individuals with stroke
Principal Investigator/ Affiliation	Miss Sunee Bovonsunthonchai / Department of Orthopedic Surgery : School of Physiotherapy, Mahidol University
Research site	Faculty of Physical Therapy and Applied Movement Science , Mahidol University
SiEc Protocol Number	281/2547
Document Approved	- Protocol - Participant information sheet - Informed consent form
Date of Approve	June 20 , 2005
Date of Expiration	June 19 , 2006

The aforementioned documents have been reviewed and approved by Ethics Committee,Faculty of Medicine Siriraj Hospital, Mahidol University, based on the Declaration of Helsinki.

Signature of Chairman

(Prof. Sumalee Nimmannit)

Signature of Dean

(Clin. Prof. Piyasakol Sakolsatayadorn)

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APPENDIX B.1

PARTICIPANT INFORMATION SHEET

เอกสารชี้แจงผู้เข้าร่วมวิจัย

ในเอกสารนี้อาจมีข้อความที่ท่านอ่านแล้วยังไม่เข้าใจ โปรดสอบถามหัวหน้าโครงการวิจัย หรือผู้แทนให้ช่วยอธิบายจนกว่าจะเข้าใจดี ท่านอาจจะขอเอกสารนี้กลับไปอ่านที่บ้านเพื่อปรึกษาหารือกับญาติพี่น้อง เพื่อนสนิท แพทย์ประจำตัวของท่าน หรือแพทย์ท่านอื่น เพื่อช่วยในการตัดสินใจเข้าร่วมการวิจัย

ชื่อโครงการ ความสัมพันธ์ระหว่างคุณลักษณะทางคลินิกและชีวกลศาสตร์ในการเดินของผู้ป่วยอัมพาตครึ่งซีก

Correlation between clinical and biomechanic characteristics of gait in individuals with stroke

ชื่อผู้วิจัย นางสาวสุนีย์ บวรสุนทรชัย

สถานที่วิจัย ห้องวิจัยวิเคราะห์การเคลื่อนไหว คณะกายภาพบำบัดและวิทยาศาสตร์การเคลื่อนไหวประยุกต์ อาคารสำนักงานอธิการบดี เชิงสะพานปิ่นเกล้า ชั้น 3 มหาวิทยาลัยมหิดล

ผู้ให้ทุน ไม่มี

โครงการวิจัยนี้ทำขึ้นเพื่อศึกษาถึง ผลทางคุณลักษณะทางชีวกลศาสตร์ของการเดินในผู้ป่วยอัมพาตครึ่งซีกซึ่งมีประโยชน์ที่คาดว่าจะได้รับ คือได้ข้อมูลพื้นฐานของความแตกต่างทางชีวกลศาสตร์ในผู้ป่วยอัมพาตครึ่งซีกเทียบกับกลุ่มควบคุมซึ่งเป็นคนปกติ และก่อให้เกิดความเข้าใจต่อผลการตรวจประเมินทางคลินิกที่จะบ่งบอกถึงความสามารถในการเดินของผู้ป่วยอัมพาตครึ่งซีก ตลอดจนสามารถนำข้อมูลที่ได้จากการศึกษามาใช้เป็นแนวทางในการรักษาและฟื้นฟูการเดินในผู้ป่วยอัมพาตครึ่งซีก

ขั้นตอนในการเก็บข้อมูลเริ่มจากทำการเก็บข้อมูลทางคลินิกโดย ผู้วิจัยซักประวัติ ตรวจวัดความดันโลหิต อัตราเต้นของหัวใจ ความตึงตัวของกล้ามเนื้อ องศาการเคลื่อนไหว การควบคุมการทำงานของกล้ามเนื้อขา การรักษาสมดุลท่าทางของร่างกาย และ ปฏิกิริยาตอบสนอง จากนั้นทำการเก็บข้อมูลการเดินโดยใช้เครื่องวิเคราะห์การเคลื่อนไหว Vicon™ Motion Analysis system ซึ่งประกอบด้วยกล้องวีดีโอ 6 ตัว ผู้เข้าร่วมวิจัยสวมชุดที่ทางผู้วิจัยเตรียมให้ ผู้วิจัยทำการติดเครื่องหมายตามตำแหน่งต่างๆของร่างกายผู้เข้าร่วมวิจัย ก่อนการเก็บข้อมูลการเดิน ผู้เข้าร่วมวิจัยทำ

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การทดลองเดินก่อนเพื่อให้เกิดความคุ้นเคย จากนั้นทำการเก็บข้อมูลการเดินที่ความเร็วปกติและเร็วกว่าปกติ 3 รอบ โดยมีมาตรการการป้องกันการล้ม ดังนี้ ผู้วิจัยและนักกายภาพบำบัดเป็นผู้คอยควบคุมดูแลป้องกันการล้มระหว่างเก็บข้อมูลการเดิน นักกายภาพบำบัดที่เดินตามป้องกันการล้มของผู้เข้าร่วมวิจัยนี้มีความแข็งแรงเพียงพอที่จะสามารถรับน้ำหนักของผู้เข้าร่วมวิจัยได้ สถานที่ที่ใช้เก็บข้อมูลการเดินเป็นห้องโล่งไม่มีสิ่งกีดขวาง ที่สองข้างทางเดินมีเบาะรองเพื่อลดการบาดเจ็บหากผู้เข้าร่วมวิจัยล้ม ผู้เข้าร่วมวิจัยจะอยู่ภายใต้การดูแลของผู้วิจัยและอาจารย์ที่ปรึกษาในการวิจัยซึ่งเป็นแพทย์ทางระบบประสาท (ศาสตราจารย์นายแพทย์ นิพนธ์ พวงวรินทร์) รวมถึงแพทย์ที่ปรึกษาของคลินิกกายภาพบำบัดคณะกายภาพบำบัดและวิทยาศาสตร์การเคลื่อนไหวประยุกต์ มหาวิทยาลัยมหิดล (ศาสตราจารย์เกียรติคุณนายแพทย์ ชูศักดิ์ เวชแพศย์) หากผู้เข้าร่วมวิจัยมีอาการผิดปกติใดๆ ผู้วิจัยจะทำการยุติการเก็บข้อมูลโดยทันที จากนั้นจะส่งปรึกษาแพทย์ทางระบบประสาทและติดต่อแพทย์ที่ปรึกษาของคลินิกกายภาพบำบัด คณะกายภาพบำบัดและวิทยาศาสตร์การเคลื่อนไหวประยุกต์ มหาวิทยาลัย มหิดล ทางโทรศัพท์หมายเลข (09) 5173145

หากมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ทราบโดยไม่ปิดบัง

ผู้เข้าร่วมการวิจัยมีสิทธิ์ถอนตัวออกจากโครงการการวิจัยเมื่อใดก็ได้ โดยไม่ต้องแจ้งให้ทราบล่วงหน้า

ข้อมูลส่วนตัวของผู้เข้าร่วมการวิจัยจะถูกเก็บรักษาไว้ ไม่เปิดเผยต่อสาธารณะเป็นรายบุคคล แต่จะรายงานผลการวิจัยเป็นข้อมูลส่วนรวม ข้อมูลของผู้เข้าร่วมการวิจัยเป็นรายบุคคลอาจมีคณะบุคคลบางกลุ่มเข้ามาตรวจสอบได้ เช่น ผู้ให้ทุนวิจัย, สถาบันหรือองค์กรของรัฐที่มีหน้าที่ตรวจสอบ, คณะกรรมการจริยธรรมฯ เป็นต้น

หากท่านได้รับการปฏิบัติที่ไม่ตรงตามที่ได้ระบุไว้ในเอกสารชี้แจงนี้ ท่านจะสามารถแจ้งให้ประธานคณะกรรมการจริยธรรมฯ ทราบได้ที่ สำนักงานคณะกรรมการจริยธรรมการวิจัยในคน ตึกอดุลยเดชวิกรม ชั้น 5 ร.พ. ศิริราช เบอร์โทร (02) 419-7000 ต่อ 6405

ข้าพเจ้าได้อ่านรายละเอียดในเอกสารนี้ครบถ้วนแล้ว

ลงชื่อ..

/ วันที่....................................

(..)

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APPENDIX B.2

CONSENT FORM

หนังสือแสดงเจตนายินยอมเข้าร่วมการวิจัย

วันที่..........……เดือน...................พ.ศ. ....…....

ข้าพเจ้า…………………………………………............................อายุ…...……......…ปี อาศัยอยู่บ้านเลขที่….........………….ถนน..........……….........................ตำบล……………………..........………..........อำเภอ………………...………...………จังหวัด………………………….รหัสไปรษณีย์........................โทรศัพท์……………………...................

ขอแสดงเจตนายินยอมเข้าร่วมโครงการวิจัย เรื่อง "ความสัมพันธ์ระหว่างคุณลักษณะทางคลินิกและชีวกลศาสตร์ในการเดินของผู้ป่วยอัมพาตครึ่งซีก" ข้าพเจ้าได้รับทราบรายละเอียดเกี่ยวกับที่มาและจุดมุ่งหมายในการทำวิจัย รายละเอียดขั้นตอนต่างๆที่จะต้องปฏิบัติหรือได้รับการปฏิบัติ ประโยชน์ที่คาดว่าจะได้รับของการวิจัยและความเสี่ยงที่อาจจะเกิดขึ้นจากการเข้าร่วมการวิจัย รวมทั้งแนวทางป้องกันและแก้ไขหากเกิดอันตรายขึ้น โดยการเข้าร่วมวิจัยในครั้งนี้ ข้าพเจ้าจะไม่ได้รับค่าตอบแทน ข้าพเจ้าได้อ่านข้อความที่มีรายละเอียดอยู่ในเอกสารชี้แจงผู้เข้าร่วมการวิจัยโดยตลอด อีกทั้งยังได้รับคำอธิบายและตอบข้อสงสัยจากหัวหน้าโครงการวิจัยเป็นที่เรียบร้อยแล้ว ข้าพเจ้าจึงสมัครใจเข้าร่วมในโครงการวิจัยนี้

หากข้าพเจ้ามีข้อข้องใจเกี่ยวกับขั้นตอนของการวิจัย หรือหากเกิดผลข้างเคียงที่ไม่พึงประสงค์จากการวิจัยขึ้นกับข้าพเจ้า ข้าพเจ้าจะสามารถติดต่อกับ นางสาว สุนีย์ บวรสุนทรชัย ได้ที่อาคารสำนักงานอธิการบดี เชิงสะพานปิ่นเกล้า ชั้น 4 มหาวิทยาลัยมหิดล โทร (02)4330140-5 ต่อ 409 หรือ โทร (06)9727888 ได้ตลอดทั้งในและนอกเวลาราชการ

หากข้าพเจ้าได้รับการปฏิบัติไม่ตรงตามที่ได้ระบุไว้ในเอกสารชี้แจงผู้เข้าร่วมการวิจัย ข้าพเจ้าสามารถติดต่อกับประธานคณะกรรมการจริยธรรมการวิจัยในคนหรือผู้แทน ได้ที่สำนักงานคณะกรรมการจริยธรรมการวิจัยในคน ตึกอดุลยเดชวิกรม ชั้น 5 รพ. ศิริราช โทร (02)419-7000 ต่อ 6405

ข้าพเจ้าได้ทราบถึงสิทธิ์ที่ข้าพเจ้าจะได้รับข้อมูลเพิ่มเติมทั้งทางด้านประโยชน์และโทษจากการเข้าร่วมการวิจัย และสามารถถอนตัวหรืองดเข้าร่วมการวิจัยได้ทุกเมื่อ โดยจะไม่มีผลกระทบต่อการบริการและการรักษาพยาบาลที่ข้าพเจ้าจะได้รับต่อไปในอนาคตและยินยอมให้ผู้วิจัยใช้ข้อมูล

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ส่วนตัวของข้าพเจ้าที่ได้รับจากการวิจัย แต่จะไม่เผยแพร่ต่อสาธารณะเป็นรายบุคคล โดยจะนำเสนอเป็นข้อมูลโดยรวมจากการวิจัยเท่านั้น

ข้าพเจ้าได้เข้าใจข้อความในเอกสารชี้แจงผู้เข้าร่วมการวิจัย และหนังสือแสดงเจตนายินยอมนี้ โดยตลอดแล้ว จึงลงลายมือชื่อไว้

ลงชื่อ...ผู้เข้าร่วมการวิจัย/ผู้แทนโดยชอบธรรม/ วันที่...........................

(...)

ลงชื่อ...ผู้ให้ข้อมูลและขอความยินยอม/หัวหน้าโครงการวิจัย/วันที่.............

(...)

ในกรณีผู้เข้าร่วมการวิจัยอ่านหนังสือไม่ออก ผู้ที่อ่านข้อความทั้งหมดแทนผู้เข้าร่วมการวิจัย คือ ....จึงลงลายมือชื่อไว้เป็นพยาน

ลงชื่อ..พยาน/ วันที่...............................

(...)

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APPENDIX C
DATA COLLECTION FORM

แบบบันทึกข้อมูลการทดลอง

กลุ่ม: ☐ **STROKE** ☐ **CONTROL** **วัน/เดือน/ปี**......................**ลำดับที่**.................
ชื่อ...**นามสกุล**...**อายุ**.................**ปี**
เพศ: ☐ **หญิง** ☐ **ชาย** **น้ำหนัก**.............................. **กก. ส่วนสูง**..........................**ซม.**
ที่อยู่...**โทร**...

1. ประวัติการเจ็บป่วย*

....
....
....

- วันเดือนปีเริ่มอาการ...
- ชนิดของ stroke ☐ Infarction ☐ Ischemic
☐ Hemorrhage ☐ อื่นๆ ....
- มีอาการอ่อนแรงแขนและขาด้าน ☐ Left ☐ Right
- ข้างที่ถนัด ☐ Left ☐ Right

2. Vital sign

- ความดัน...mmHg
- ชีพจร...bpm

3. Cognitive status*

Thai Mental State Examination (TMSE) ..../ 30คะแนน

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4. องศาการเคลื่อนไหว (Passive Range of Motion)

4.1 Hip joint	**Left**			**Right**		
- Flexion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Extension	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Abduction	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Adduction	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Internal rotation	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- External rotation	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
4.2 Knee joint	**Left**			**Right**		
- Flexion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Extension	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
4.3 Ankle joint	**Left**			**Right**		
- Plantarflexion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Dorsiflexion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Inversion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited
- Eversion	☐ Normal	☐ Decreased	☐ Limited	☐ Normal	☐ Decreased	☐ Limited

5. การรับความรู้สึก (Sensation)*

5.1 Exteroceptive sense						
Light touch	**Left**			**Right**		
- Arm	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Forearm	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Hand	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Thigh	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Shank	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Foot	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss

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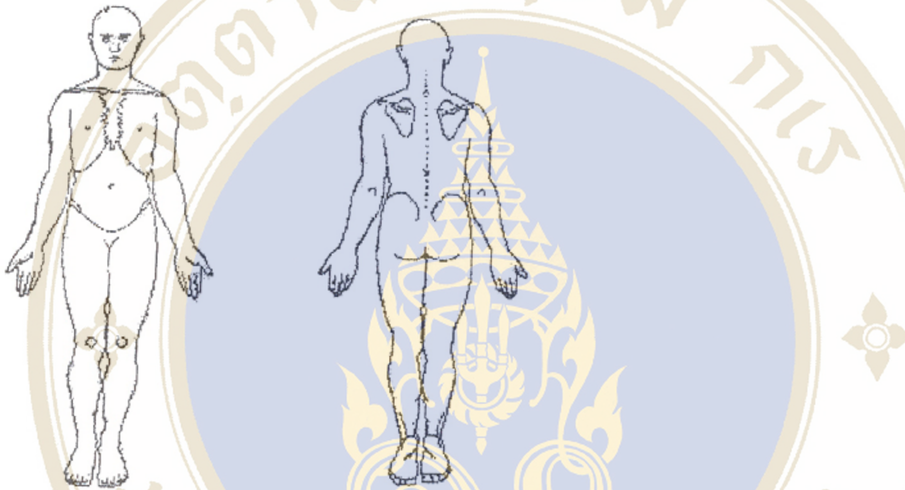
Pinprick	Left			Right		
- Arm	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Forearm	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Hand	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Thigh	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Shank	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Foot	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss



5.2 Proprioceptive sense						
Joints	Left			Right		
- Hip joint	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Knee joint	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss
- Ankle joint	☐ Intact	☐ Impaired	☐ Loss	☐ Intact	☐ Impaired	☐ Loss

6. ปฏิกิริยาตอบสนอง (Deep tendon reflex)*

Joints	Left				Right			
- Elbow	☐ 3+	☐ 2+	☐ 1+	☐ 0	☐ 3+	☐ 2+	☐ 1+	☐ 0
- Knee	☐ 3+	☐ 2+	☐ 1+	☐ 0	☐ 3+	☐ 2+	☐ 1+	☐ 0
- Ankle	☐ 3+	☐ 2+	☐ 1+	☐ 0	☐ 3+	☐ 2+	☐ 1+	☐ 0

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7. Anthropometric data

Anthropometric	Left (cm)	Right (cm)
- ความกว้างของข้อศอก (Elbow width)		
- ความหนาของมือ (Hand thickness)		
- ความยาวขา (Leg length): ASIS-Medial malleolus		
- ความกว้างของข้อเข่า (Knee width)		
- ความกว้างของข้อเท้า (Ankle width)		

8. ความตึงตัวกล้ามเนื้อ (Muscle tone): MAS Grade 0-4*

ความตึงตัวกล้ามเนื้อ (Muscle tone)	Left (cm)	Right (cm)
- Hip adductors		
- Hip extensors		
- Ankle plantarflexors		
- Ankle invertors		
- Knee extensors		

- Ankle clonus ………………..……. beats

- Babinski's sign……………….…….

9. การทำงานของประสาทยนต์ส่วนขา (Lower extremity motor function)*

Fugl-Meyer Scale……….../ 34 คะแนน

10. ความสมดุล (balance)*

Berg Balance Scores…………….../ 56คะแนน

Note: * ตรวจเฉพาะกลุ่ม stroke

....

....

....

....

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APPENDIX D

THAI MENTAL STATE EXAM (TMSE)

แบบทดสอบสมรรถภาพสมองของไทย

All subjects were determined the cognitive status by TMSE before participated the study. TMSE composes of 6 domains: orientation, registration, attention, calculation, language, and recall. It was developed to use in assessing the cognitive status in Thai populations by Train the Brain Forum. The maximum score of this test is 30 scores. Criteria of this assessment were set at the score of more than or equal to 23 scores.

1. ORIENTATION (6 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
1	วันนี้ วันอะไรของสัปดาห์ (จ. อ. พ. พฤ. ศ.)	....	....
1	วันนี้ วันที่เท่าไร	....	....
1	เดือนนี้ เดือนอะไร	....	....
1	ขณะนี้ เป็นช่วง(ตอน)ไหนของวัน (เช้า เที่ยง บ่าย เย็น)	....	....
1	ที่นี่ที่ไหน	....	....
1	คนที่เห็นในภาพมีอาชีพอะไร	....	....

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2. REGISTRATION (3 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
3	ผู้ทดสอบบอกชื่อของ 3 อย่าง ห่างกัน 1 วินาที (ต้นไม้ รถยนต์ มือ) ครั้งเดียว แล้วให้ผู้ถูกทดสอบบอกให้ครบตามที่บอก (1 คะแนน) * จากนั้นให้ผู้ถูกทดสอบจำ แล้วบอกว่าจะกลับมาถามใหม่	....	....

3. ATTENTION (5 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
	ให้บอกวันย้อนหลังเริ่มจากวันเสาร์จนครบ 5 วัน (ตอบซ้ำได้ 1 ครั้ง)		
1	- ศุกร์	....	....
1	- พฤหัสบดี	....	....
1	- พุธ	....	....
1	- อังคาร	....	....
1	- จันทร์	....	....

4. CALCULATION (3 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
	ให้คำนวณ 100-7 ไปเรื่อยๆ 3 ครั้ง (แต่ละช่วงไม่เกิน 1 นาที)		
1	100-7	....	....
1	93-7	....	....
1	86-7	....	....

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5. LANGUAGE (10 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
1	- "เราเรียกสิ่งนี้ว่าอะไร" ชี้ไปที่นาฬิกา	....	....
1	- "เราเรียกสิ่งนี้ว่าอะไร" ชี้ไปที่เสื้อ	....	....
1	- ฟังประโยคต่อไปนี้แล้วพูดตาม "ยายพาหลานไปซื้อขนมที่ตลาด"	....	....
	จงทำตามคำสั่งต่อไปนี้ (3 ขั้นตอน) ให้กระดาษเปล่าแก่ผู้ถูกทดสอบ		
1	- หยิบกระดาษด้วยมือขวา	....	....
1	- พับกระดาษเป็นครึ่งแผ่น	....	....
1	- ส่งกระดาษให้ผู้ทดสอบ	....	....
1	ให้ผู้ถูกทดสอบอ่านข้อความในกระดาษที่ให้ แล้วทำตาม "หลับตา"	....	....
1	กล้วยกับส้มเหมือนกันคือเป็นผลไม้ แมวกับลิงเหมือนกันคือเป็น (สัตว์ หรือ สิ่งมีชีวิต)	....	....
2	จงวาดภาพต่อไปนี้ให้เหมือนตัวอย่างมากที่สุดเท่าที่ท่านจะสามารถทำได้	....	....

6. RECALL (3 คะแนน)

คะแนนเต็ม	คำถาม	คำตอบ	คะแนนที่ได้
3	ให้ทวนชื่อของ 3 อย่าง (ต้นไม้ รถยนต์ มือ)	....	....

จาก: กลุ่มฟื้นฟูสมรรถภาพสมอง สารศิริราช ปีที่ 45 ฉบับที่ 6 มิถุนายน 2536 (359-374)

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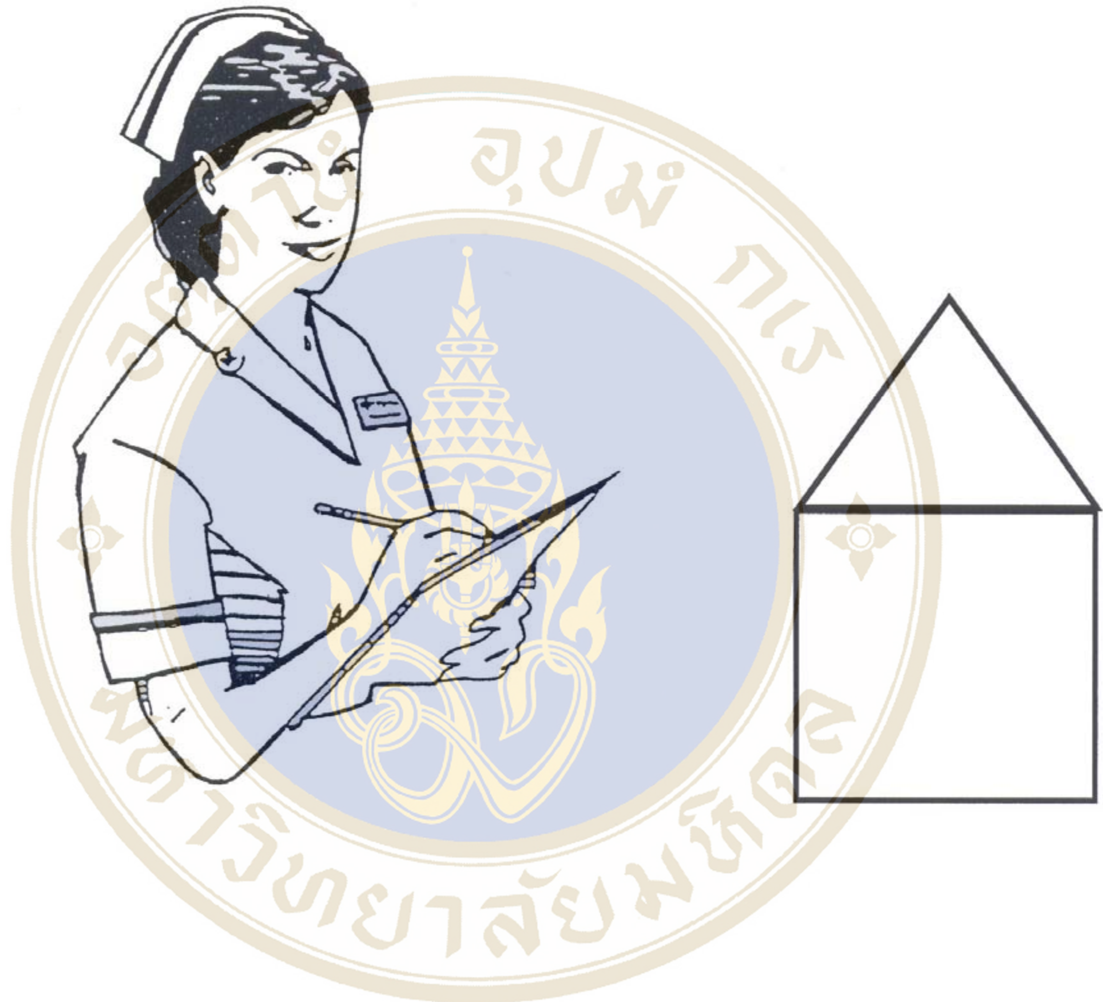

หลับตา

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APPENDIX E
MUSCLE TONE ASSESSMENT

Muscle tone of five lower extremity muscle groups was assessed by the Modified Ashworth Scale (MAS). The descriptions of grading muscle tone (1) and position test were presented as followed;

Table E.1 Grading of muscle tone

Grade	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and resistance at the end of the range of motion when the affected part (s) is moved in flexion or extension
1+	Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM
2	More marked increase in muscle tone through most of ROM, but affected part(s) easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected part(s) rigid in flexion or extension

The un-affected side will be assessed first and then on the affected side for individual comparison. The methods for muscle tone testing are as following:

1. Hip adductors: Supine lying, researcher stands on the side of subject, places hands on the knee and the ankle, then passively abducts the subject’s leg.
2. Hip extensors: Supine lying, researcher places hands on the subject’s leg and passive in flexion direction with the knee extension.

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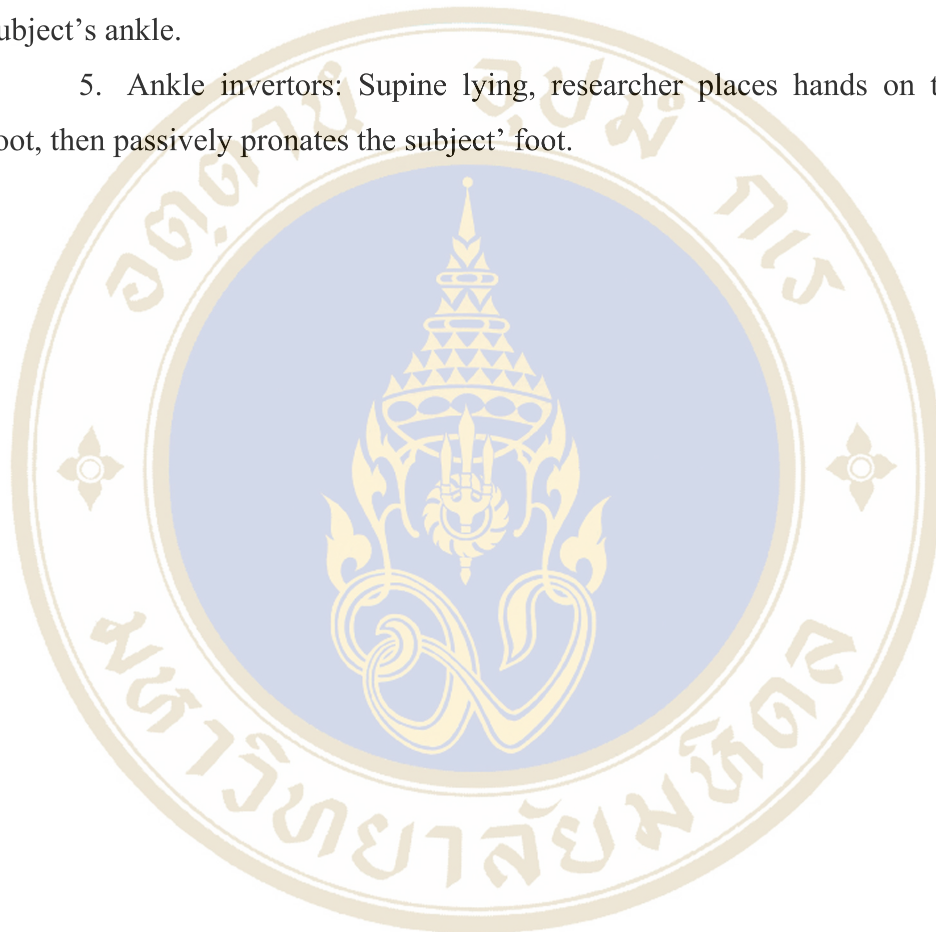
3. Knee extensors: Side lying with support, hip in the neutral position (0 degrees). Researcher places hands on the subject's thigh and ankle and passively flexes the subject's knee.

4. Ankle plantarflexors: Supine lying, researcher places hands on the proximal part of the ankle and the heel of subject, then, passively dorsiflexes the subject's ankle.

5. Ankle invertors: Supine lying, researcher places hands on the subject's foot, then passively pronates the subject' foot.



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APPENDIX F
LOWER EXTREMITY MOTOR ASSESSMENT

Motor function was assessed by Fugl-Meyer assessment scale, the extensively used for detect the recovery stage of stroke patient. The total scale allocates 24 scores to sensation, 14 scores to balance, 66 scores to the upper extremity, and 34 scores to lower extremity function (1). Only the lower extremity function was determined in this study. The description of scoring method is presented as follow;

Lower extremity motor function of Fugl-Meyer Assessment

1. Patient in the supine position, patellar and archilles reflexes are evaluated.

Scores: 0: No reflexes activity

2: Reflex activity can be elicited in flexors and/or extensors

Maximum score is 4

2. The following stages are defined as the corresponding stages for the extremity.

- Flexor synergy: The patient in supine position is instructed to flex hip, knee, and ankle joints maximally. The hip usually is abducted and outwards rotated simultaneously. During this motion the distal tendons of the knee flexors should be palpated in order to ascertain that active flexion of knee occurs.

Scores: 0: The specific detail cannot be performed

1: The detail can be performed only partly

2: The detail is performed throughout the total range of motion of each of the three joints.

- Extensor synergy: From the “end points” of the flexor synergy the patient should extend hip, knee, and ankle joints, resistance being exerted in order to eliminate gravitational facilitation of the maneuver. Hip abduction against resistance is also performed. (The hip adduction may be evaluated in combination with hip extension).

Scores: 0: The specific detail cannot be performed

1: Some little strength,

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2: Normal or nearly normal strength (compared with unaffected limb).

Maximum score is 14

3. Patient in the sitting position, knees free of the bedside of the edge of the chair, is asked to

- Flex knee beyond 90^0.

Scores: 0: No active motion,

1: From a somewhat extended position, the knee can actively be flexed towards but not beyond 90^0 (simultaneously the tendons of the hamstrings are palpated),

2: The knee can be flexed beyond 90^0

- Dorsiflex the ankle joint

Scores: 0: Cannot

1: Impaired active flexion

2: Normal dorsiflexion (compared with unaffected limb)

Maximum score is 4

4. The standing patient is instructed to

- Flex knee beyond 90^0, the hip at 0^0 or further extended.

Scores: 0: The knee cannot at all be flexed if the hip is not simultaneously flexed

1: The knee cannot be flexed fully to 90^0 and/or the hip is flexed during the performance of this motion

2: The knee can be flexed beyond 90^0 and the hip at 0^0

- Dorsiflex the ankle joint

Scores: 0: Cannot

1: Impaired active flexion

2: Normal dorsiflexion (compared with unaffected limb)

Maximum score is 4

5. The normality of muscle reflexes is recorded

Scores: 0: No reflexes activity

2: Reflex activity can be elicited in flexors and/or extensors

Maximum score is 2

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6. Coordination/Speed

The patient in supine position is instructed to bring heel to knee cap of the opposite leg 5 times in as rapid succession as possible.

Tremors, dysmetria, swiftness of motion are recorded.

- Tremor

Scores: 0: Marked tremor
1: Slight tremor
2: No tremor

- Dysmetria

Scores: 0: Pronounced dysmetria
1: Slight dysmetria
2: No dysmetria

- Speed

Scores: 0: Six seconds slower than unaffected side
1: Two to 5 seconds slower
2: Less than 2 seconds difference

Maximum score is 6

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Table F.1 Fugl-Meyer Assessment of physical performance

Area	Test	Scoring Criteria	Attained Score
LOWER EXTREMITY (supine)	**I.** Reflex activity-tested in supine position Achilles …… Patellar ……	0- No reflex activity 2- Reflex activity	/4
SUPINE	**II. A.** Flexor Synergy Hip flexion …… Knee flexion …… Ankle dorsiflexion …… **B.** Extensor synergy (motion is resisted) Hip extension …… Adduction …… Knee extension …… Ankle plantarflexion ……	**A.** 0- Cannot be performed 1- Partial motion 2- Full motion **B.** 0- No motion 1- Weak motion 2- Almost full strength compared to normal	/14
SITTING (Knees free of chair)	**III.** Movement Combining Synergies **A.** Knee flexion beyond 90° ….. **B.** Ankle dorsiflexion ……	**A.** 0- No active motion 1- From slightly extended position knee can be flexed but not beyond 90° 2- Knee flex beyond 90° **B.** 0- No active flexion 1- Incomplete active flexion 2- Normal dorsiflexion	/4
STANDING	**IV.** Movement out of Synergy Hip at 0° **A.** Knee flexion beyond 90° …… **B.** Ankle dorsiflexion ……	**A.** 0- Knee cannot flex without hip flexion 1- Knee begins flexion without hip flexion, but doesn't get to 90, or hip flexes during motion 2- Full motion is described **B.** 0- No active motion 1- Partial motion 2- Full motion	/4
SITTING	**V.** Normal Reflexes …… Knee flexors Patellar Achilles	0- 2 of the 3 are markedly hyperactive 1- One of reflex is hyper active or 2 reflexes are lively 2- No more than 1 reflex lively and no reflexes markedly hyperactive	/2
SUPINE	**VI.** Coordination/Speed Heel to opposite knee (5 repetitions in rapid succession) **A.** Tremor …… **B.** Dysmetria …… **C.** Speed ……	**A.** 0- Marked tremor 1- Slight tremor 2- No tremor **B.** 0- Pronoumced or unsystematic 1- Slight or systematic 2- No dysmetria **C.** 0- Six seconds slower than unaffected side 1- Two to 5 seconds slower 2- Less than 2 seconds difference	/6
TOTAL MAXIMUM LOWER EXTREMITY SCORE			**/34**

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APPENDIX G
BALANCE ASSESSMENT

Balance was assessed by the Berg balance Scale (BBS). There are 14 functional items which frequently performs in daily activity living contain in this assessment. Maximum score of the BBS is 56 scores (1). In the present study, items 1, 5, 10, 11, 13, and 14 were classified into the scores of the un-affected and the affected performance. The scores of BBS were presented with the sum scores of 14 items of the un-affected and the affected side. Descriptions and summarization of the BBS were presented in the following;

Berg Balance Scale

1. Sitting to standing

Instruction: Please stand up. Try not to use your hands for support.

( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or to stabilize
( ) 0 needs moderate or maximal assist to stand

2. Standing unsupported

Instruction: Please stand for two minutes without holding.

( ) 4 able to stand safely 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unassisted

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

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3. Sitting with back unsupported but feet supported on floor or on a stool

Instruction: Please sit with arms folded for 2 minutes.

( ) 4 able to sit safely and securely 2 minutes

( ) 3 able to sit 2 minutes under supervision

( ) 2 able to sit 30 seconds

( ) 1 able to sit 10 seconds

( ) 0 unable to sit without support 10 seconds

4. Standing to sitting

Instruction: Please sit down.

( ) 4 sits safely with minimal use of hands

( ) 3 controls descent by using hands

( ) 2 uses back of legs against chair to control descent

( ) 1 sits independently but has uncontrolled descent

( ) 0 needs assistance to sit

5. Transfers

Instruction: Arrange chairs(s) for a pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.

( ) 4 able to transfer safely with minor use of hands

( ) 3 able to transfer safely definite need of hands

( ) 2 able to transfer with verbal cueing and/or supervision

( ) 1 needs one person to assist

( ) 0 needs two people to assist or supervise to be safe

6. Standing unsupported with eyes closed

Instruction: Please close your eyes and stand still for 10 seconds.

( ) 4 able to stand 10 seconds safely

( ) 3 able to stand 10 seconds with supervision

( ) 2 able to stand 3 seconds

( ) 1 unable to keep eyes closed 3 seconds but stays steady

( ) 0 needs help to keep from falling

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7. Standing unsupported with feet together

Instruction: Place your feet together and stand without holding.

( ) 4 able to place feet together independently and stand 1 minute safely

( ) 3 able to place feet together independently and stand for 1 minute with supervision

( ) 2 able to place feet together independently and to hold for 30 seconds

( ) 1 needs help to attain position but able to stand 15 seconds feet together

( ) 0 needs help to attain position and unable to hold for 15 seconds

8. Reaching forward with outstretched arm while standing

Instruction: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently >25 cm (10 inches)

( ) 3 can reach forward >12.5 cm safely (5 inches)

( ) 2 can reach forward >5 cm safely (2 inches)

( ) 1 reaches forward but needs supervision

( ) 0 loses balance while trying/ requires external support

9. Pick up object from the floor from a standing position

Instruction: Pick up the shoe/slipper which is placed in front of your feet.

( ) 4 able to pick up slipper safely and easily

( ) 3 able to pick up slipper but needs supervision

( ) 2 unable to pick up but reaches 2-5cm (1-2 inches) from slipper and keeps balance independently

( ) 1 unable to pick up and needs supervision while trying

( ) 0 unable to try/needs assist to keep from losing balance or falling

10. Turning to look behind over left and right shoulders while standing

Instruction: Turn to look **directly** behind you over toward left shoulder. Repeat to the right. Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.

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( ) 4 looks behind from both sides and weight shifts well

( ) 3 looks behind one side only other side shows less weight shift

( ) 2 turns sideways only but maintains balance

( ) 1 needs supervision when turning

( ) 0 needs assist to keep from losing balance or falling

11. Turn 360 degrees

Instruction: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less

( ) 3 able to turn 360 degrees safely one side only in 4 seconds or less

( ) 2 able to turn 360 degrees safely but slowly

( ) 1 needs close supervision or verbal cueing

( ) 0 needs assistance while turning

12. Placing alternate foot on step or stool while standing unsupported

Instruction: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds

( ) 3 able to stand independently and complete 8 steps >20 seconds

( ) 2 able to complete 4 steps without aid with supervision

( ) 1 able to complete >2 steps needs minimal assist

( ) 0 needs assistance to keep from falling/unable to try

13. Standing unsupported on foot in front

Instruction: (demonstrate to subject)

Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width)

( ) 4 able to place foot tandem independently and hold 30 seconds

( ) 3 able to place foot ahead of other independently and hold 30 seconds

( ) 2 able to take small step independently and hold 30 seconds

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( ) 1 needs help to step but can hold 15 seconds

( ) 0 loses balance while stepping or standing

14. Standing on one leg

Instruction: Stand on one leg as long as you can without holding.

( ) 4 able to lift leg independently and hold >10 seconds

( ) 3 able to lift leg independently and hold 5-10 seconds

( ) 2 able to lift leg independently and hold = or >3 seconds

( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently

( ) 0 unable to try or needs assist to prevent fall

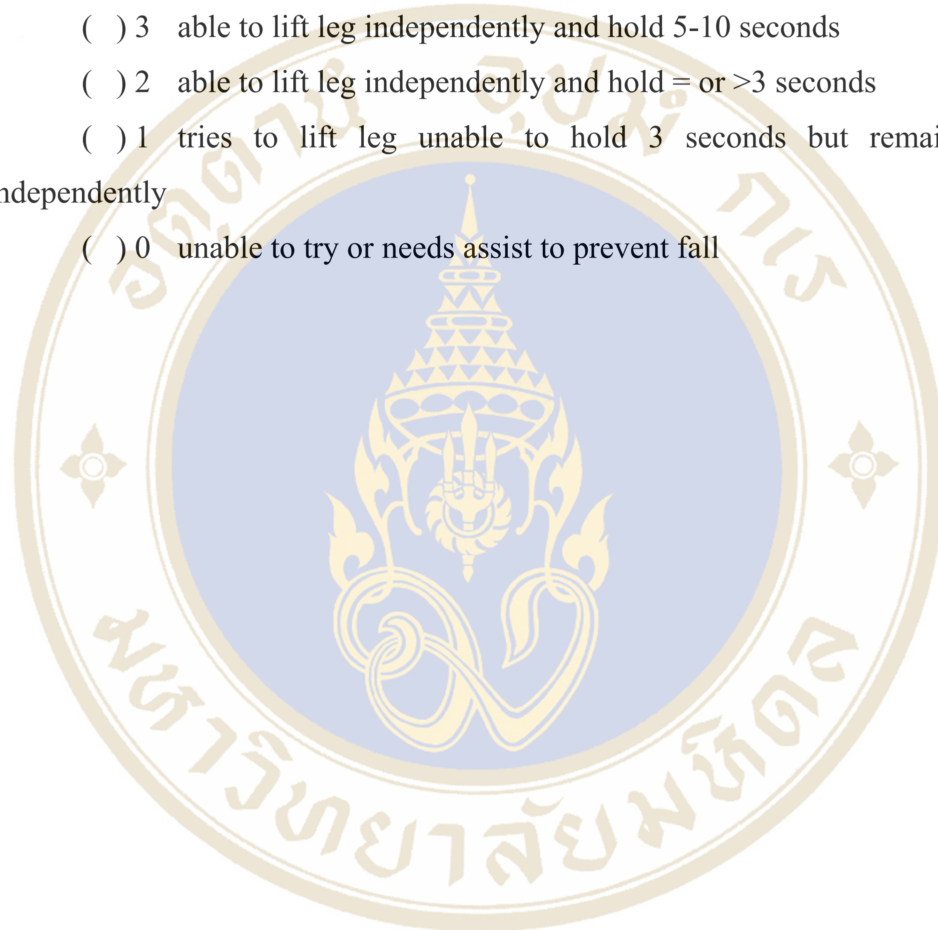

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Table G.1 Berg Balance Scale

Items	Score		Items	Score	
1. Sitting to standing	A	S	**8. Reaching forward with outstretched arm while standing**		
4: able to stand without using hands and stabilize indep 3: able to stand indep using hands 2: able to stand using hands after several tries 1: needs minimal aid to stand or to stabilize 0: needs mod or max assist to stand			4: can reach forward confidently >25 cm 3: can reach forward >12.5 cm safely 2: can reach forward >5 cm safely 1: reaches forward but needs supervision 0: loses balance while trying/ requires ext. support		
2. Standing unsupported			**9. Pick up object from the floor from a standing position**		
4: able to stand safely 2 min 3: able to stand 2 min with supervision 2: able to stand 30 s unsupported 1: needs several tries to stand 30 s unsupported 0: unable to stand 30 s unassisted			4: able to pick up safely and easily 3: able to pick up but needs supervision 2: unable to pick up but reaches 2-5cm and keeps balance indep 1: unable to pick up and needs supervision 0: unable to try/needs assist to keep from falling		
3. Sitting with back unsupported, feet supported on floor			**10. Turning to look behind over Lt and Rt sh while stand**	A	S
4: able to sit safely and securely 2 min 3: able to sit 2 min under supervision 2: able to sit 30 s 1: able to sit 10 s 0: unable to sit without support 10 s			4: looks behind from both sides and wt shifts well 3: looks behind one side only other side shows less wt shift 2: turns sideways only but maintains balance 1: needs supervision when turning 0: needs assist to keep from losing balance or falling		
4. Standing to sitting			**11. Turn 360 degrees**	A	S
4: sits safely with minimal use of hands 3: controls descent by using hands 2: uses back of legs against chair to control descent 1: sits indep but has uncontrolled descent 0: needs assistance to sit			4: able to turn 360^0 safely in $\le$ 4 s 3: able to turn 360^0 safely one side only in $\le$ 4 s 2: able to turn 360^0 safely but slowly 1: needs close supervision or verbal cueing 0: needs assistance while turning		
5. Transfers	A	S	**12. Placing alternate foot on step while stand unsupported**		
4: able to transfer safely with minor use of hands 3: able to transfer safely definite need of hands 2: able to transfer with verbal cueing and/or supervision 1: needs one person to assist 0: needs two people to assist or supervise to be safely			4: able to stand indep and safely and complete 8 steps in 20 s 3: able to stand independently and complete 8 steps >20 s 2: able to complete 4 steps without aid with supervision 1: able to complete >2 steps needs minimal assist 0: needs assistance to keep from falling/unable to try		
6. Standing unsupported with eyes closed			**13. Standing unsupported one foot in front**	A	S
4: able to stand 10 s safely 3: able to stand 10 s with supervision 2: able to stand 3 s 1: unable to keep eyes closed 3 s but stays steady 0: needs help to keep from falling			4: able to place foot tandem indep and hold 30 s 3: able to place foot ahead of other indep and hold 30 s 2: able to take small step indep and hold 30 s 1: needs help to step but can hold 15 s 0: loses balance while stepping or standing		
7. Standing unsupported with feet together			**14. Standing on one leg**	A	S
4: able to place feet together indep and stand 1 min safely 3: able to place feet together indep and stand for 1 min with supervision 2: able to place feet together indep and to hold for 30 s 1: needs help to attain position but able to stand for 15 s feet together 0: needs help to attain position and unable to hold for 15 s			4: able to lift leg indep and hold >10 s 3: able to lift leg indep and hold 5-10 s 2: able to lift leg indep and hold $\ge$ 3 s 1: tries to lift leg unable to hold 3 s but remains standing indep 0: unable to try or needs assist to prevent fall		

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APPENDIX H
TEST-RETEST RELIABILITY OF GAIT EVENTS LABEL

The purpose of the test was to determine test-retest reliability of the researcher (Ms. Sunee Bovonsunthonchai) in labeling the gait events.

Procedure

The hemiplegic gait cycles were selected to detect the researcher test-retest reliability. Twelve times of initial contact and toe off events of affected and un-affected sides were identified. Both initial contact and toe off events were indicated by toe and heel marker trajectories in the sagittal plane view via Vicon™ Workstation software. Initial contact event is the first contact event of the foot to the ground which might be by heel or fore-foot contact. Toe off event is the last event which foot contact to the ground prior to the swing period. In addition, gait events were recorded in frames and were labeled twice approximately 1 hour apart.

Data Analysis

Intraclass correlation coefficient (ICC 3,1) at the significance level of 0.05 was used to determine the test-retest reliability for each event.

Results

Test-retest reliability of all events including the initial contact and toe off of affected and un-affected sides in individuals with stroke gait were 1.000 as shown in Table H.1. The raw data of two trials labeling are in Table H.2.

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Table H.1 Intraclass correlation coefficient (ICC 3,1)

Anthropometrics	ICC 3,1
1. IC: Affected side	1.000
2. IC: Unaffected side	1.000
3. TO: Affected side	1.000
4. TO: Unaffected side	1.000

Note: IC: Initial contact
TO: Toe off

Table H.2 Test-retest reliability of gait events at initial contact (IC) and toe off (TO) (frames)

No.	Affected side				No.	Un-affected side			
	Trial 1		Trial 2			Trial 1		Trial 2	
	IC1	TO1	IC2	TO2		IC1	TO1	IC2	TO2
1.	394	480	394	480	1.	241	332	241	332
2.	540	628	541	628	2.	365	452	365	451
3.	678	750	679	749	3.	486	572	486	572
4.	787	265	789	266	4.	610	688	609	689
5.	315	389	316	389	5.	260	342	259	341
6.	435	508	434	509	6.	380	465	380	465
7.	557	633	557	633	7.	504	589	503	589
8.	675	161	675	161	8.	629	221	630	221
9.	208	280	207	281	9.	396	479	395	480
10.	330	404	331	404	10.	541	628	541	628
11.	451	529	452	529	11.	678	748	678	748
12.	575	651	575	651	12.	790	335	790	335

Note: IC1: Initial contact at the first time
IC2: Initial contact at the second time
TO1: Toe off at the first time
TO2: Toe off at the second time

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APPENDIX I
EFFECT OF SIDE TO GAIT BIOMECHANICS

The purpose was to determine the differences of gait biomechanics data between left and right sides in the control group. The results of this process were used in the comparison of individuals with stroke and control groups.

Procedure

Kinematic and kinetic data were assessed the differences of left and right sides. Kinematic data was composed of joint angles of hip, knee, and ankle at the initial contact and toe-off events. Kinetic data was composed of the vertical (Z), medio-lateral (X), and antero-posterior (Y) ground reaction forces. To compare the differences of left and right sides, ten normal subjects were tested the influence of side. Each kinematic and kinetic parameter was averaged from 3 walking trials per subject.

Data Analysis

Kolmogorov smirnov goodness of fit test was needed to determine the distribution of the data before comparing the left and right sides. Paired t-test and Wilcoxon sign rank test were used to test the differences of the data if the results show normal and non-normal distribution respectively. The significance level was set at 0.05 for determining the differences between sides.

Results

The biomechanics data of the left and right sides for the control showed some differences of joint angles (degrees) at initial contact and toe off events both during comfortable and fast gait speeds (see Tables I.1 and I.2).

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At comfortable gait speed, significant differences in the left and right leg data demonstrated at joint angles in all planes of movement. In the sagittal plane, the differences between the left and right sides were at hip during initial contact ($p=0.0035$) and toe off ($p=0.001$). In the frontal plane, the difference between the left and right sides was at knee during toe off ($p=0.007$). In the transverse plane, the differences between the left and right sides were at hip and knee joints. The differences between the left and right sides of the hip were showed at initial contact ($p=0.003$) and toe off ($p=0.011$), while the difference at the knee was shown at initial contact ($p=0.038$).

At fast gait speed, significant differences between the left and right sides were in the frontal and the transverse planes. In the frontal plane, the differences between sides were at ankle and knee joints during initial contact (the ankle: $p=0.028$ and the knee: $p=0.044$). In addition, knee angle showed significant ($p=0.026$) difference at toe off. In the transverse plane, the significant difference showed in all joints when initial contact. However, only hip joint had significant ($p=0.023$) difference at toe off.

In addition, there were significant differences in peak ground reaction forces (×10N) in all medio-lateral force (X1, X2, and X3) both during comfortable and fast gait speeds ($p<0.05$) (see Tables I.3 and I.4).

As many variables presented significant difference between the left and right sides, it is, therefore, will average both the left and the right side data as a representative average value for the control group in this study.

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Table I.1 Joint angles of ankle, knee, and hip (degrees) at initial contact (IC) and toe off (TO) events during comfortable gait speed

Planes	Joints	Angular displacements during comfortable gait speed									
		IC-Left		IC-Right		p-value*	TO-Left		TO-Right		p-value*
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Sagittal	Ankle	0.30	7.67	1.56	5.78	0.316	-7.91	11.56	-12.63	3.70	0.199
	Knee	8.69	3.26	6.43	2.75	0.121	38.87	3.28	39.48	5.32	0.594
	Hip	27.93	6.55	26.22	5.00	0.035*	-5.65	7.04	-4.35	6.83	0.001*
Frontal	Ankle	0.50	0.82	1.06	1.49	0.332	0.51	1.12	1.05	1.31	0.324
	Knee	-0.72	3.74	0.15	3.03	0.238	4.70	4.08	8.66	5.06	0.007*
	Hip	-0.82	3.26	0.37	3.14	0.160	-5.60	4.45	-4.56	3.03	0.384
Transverse	Ankle	-0.64	4.47	-3.59	5.77	0.144	-0.77	5.53	-3.45	5.93	0.199
	Knee	-2.54	3.71	-8.06	6.01	0.038*	-4.33	6.10	-9.14	3.36	0.023
	Hip	-11.69	5.79	-4.60	7.41	0.030*	0.36	5.26	7.55	8.63	0.011*

Note: * paired-t-test at 0.05 significant level

Table I.2 Joints angle of ankle, knee, and hip (degrees) at initial contact (IC) and toe off (TO) events during fast gait speed

Planes	Joints	Angular displacements during fast gait speed									
		IC-Left		IC-Right		p-value*	TO-Left		TO-Right		p-value*
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Sagittal	Ankle	1.98	8.82	3.22	5.04	0.447	-15.14	6.99	-16.54	3.30	0.404
	Knee	9.39	5.08	9.84	3.50	0.785	38.90	3.34	38.93	5.43	0.979
	Hip	31.92	6.39	29.91	4.57	0.093	-8.11	7.49	-8.09	7.22	0.976
Frontal	Ankle	0.39	0.75	1.52	1.19	0.028*	0.52	1.45	1.21	1.02	0.200
	Knee	-1.11	3.72	0.62	3.45	0.044*	4.18	4.20	7.48	5.72	0.026*
	Hip	-2.58	4.11	-1.00	3.75	0.114	-6.07	4.38	-5.68	2.87	0.722
Transverse	Ankle	-0.31	4.13	-5.10	4.80	0.007*	-0.70	6.17	-4.21	5.17	0.067
	Knee	-1.21	4.69	-7.68	7.19	0.017*	-3.40	6.53	-7.29	3.62	0.055
	Hip	-13.67	5.63	-4.22	9.17	0.013*	0.00	5.58	6.48	9.23	0.023*

Note: * paired-t-test at 0.05 significant level

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Table I.3 Ground reaction forces (GRFs) (N/kg) and time to peak forces during comfortable gait speed (×10% gait cycle)

Comfortable gait speed											
GRFs	**Left**		**Right**		**p-value***	**Time**	**Left**		**Right**		**p-value***
	Mean	**SD**	**Mean**	**SD**			**Mean**	**SD**	**Mean**	**SD**	
X1	-0.23	0.12	-0.46	0.16	0.000*	**X1**	0.02	0.01	0.02	0.00	0.195
X2	0.65	0.14	0.43	0.10	0.000*	**X2**	0.16	0.03	0.16	0.04	0.710
X3	0.72	0.13	0.57	0.11	0.001*	**X3**	0.47	0.03	0.47	0.03	0.889
Y1	-1.54	0.46	-1.51	0.40	0.744	**Y1**	0.08	0.01	0.08	0.02	0.731
Y2	2.13	0.31	2.02	0.29	0.250	**Y2**	0.54	0.01	0.55	0.02	0.120
Z1	10.43	1.01	10.27	0.82	0.408	**Z1**	0.15	0.02	0.15	0.02	0.717
Z2	11.20	0.96	11.08	1.00	0.341	**Z2**	0.47	0.02	0.47	0.02	0.526

Note: * paired-t-test at 0.05 significant level

Table I.4 Ground reaction forces (GRFs) (N/kg) and time to peak forces during fast gait speed (×10% gait cycle)

Fast gait speed											
GRF	**Left**		**Right**		**p-value***	**Time**	**Left**		**Right**		**p-value***
	Mean	**SD**	**Mean**	**SD**			**Mean**	**SD**	**Mean**	**SD**	
X1	-0.31	0.19	-0.72	0.22	0.000*	**X1**	0.02	0.01	0.02	0.00	0.267
X2	0.82	0.19	0.59	0.21	0.000*	**X2**	0.16	0.03	0.16	0.04	0.939
X3	0.72	0.13	0.62	0.14	0.032*	**X3**	0.45	0.04	0.46	0.04	0.697
Y1	-2.48	0.67	-2.39	0.74	0.333	**Y1**	0.08	0.01	0.09	0.01	0.504
Y2	2.74	0.55	2.81	0.34	0.546	**Y2**	0.51	0.01	0.51	0.02	0.165
Z1	12.27	1.48	12.45	1.52	0.364	**Z1**	0.13	0.01	0.12	0.01	0.411
Z2	11.57	1.15	11.74	1.16	0.318	**Z2**	0.45	0.01	0.46	0.01	0.128

Note: * paired-t-test at 0.05 significant level

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APPENDIX J
ERROR OF MEASUREMENT

The purpose of measure of error was to determine the accuracy of angle calculation by comparing the calculated angles from Vicon^{TM} Motion Analysis System and reference angles.

Procedure

Prior to test, system was calibrated to allow software calculating the relative location and orientation of all cameras. There were eight reflective markers with 10 mm in diameters attached on the cardboard constructing 6 angles. The angles were placed in 30, 60, 90, 120, 150, and 180 degrees as illustrated in Figure J.1.

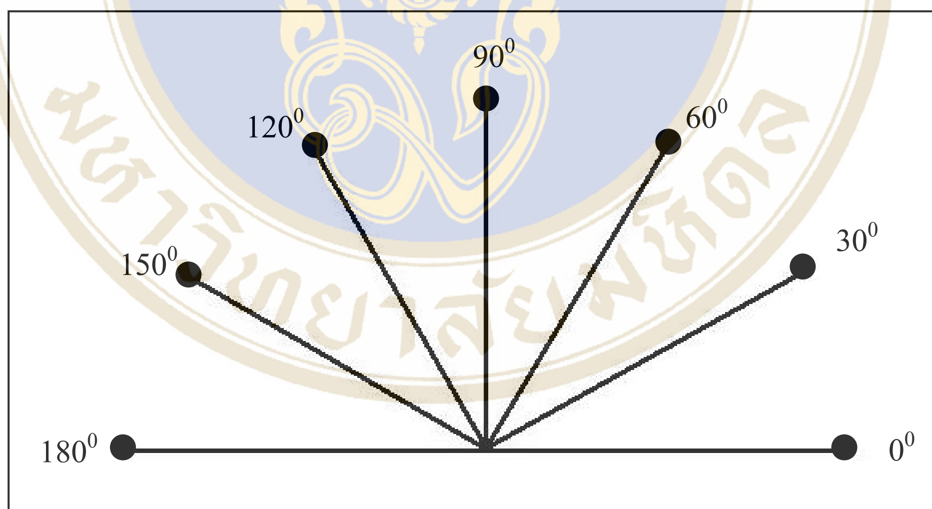

Figure J.1 The cardboard with the angles between 30 and 180 degrees.

The cardboard was filmed in static and dynamic motions by 6 video cameras of Vicon^{TM} Motion Analysis System. In static, cardboard was placed in vertical at the middle path of the walkway. In dynamic motion, cardboard was filmed during walking along 10-m walkway with statically and wavily holds. The angles on the cardboard were calculated by Vicon^{TM} Workstation software comparing with the reference angles as shown in Table J.1.

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Table J.1 Reference and calculated angles

Condition	Reference angle (Ref) (degrees)	Calculated angles (Cal) (degrees)	Different value (Cal-ref) (degrees)
Static	30	30.1	0.1
	60	59.6	-0.4
	90	89.8	-0.2
	120	119.8	-0.2
	150	150	0
	180	179.5	-0.5
Dynamic with statically hold	30	30.5	0.5
	60	59.5	-0.5
	90	89.9	-0.1
	120	119.8	-0.2
	150	150	0
	180	179.5	-0.5
Dynamic with wavily hold	30	30.6	0.6
	60	59.5	-0.5
	90	89.9	-0.1
	120	119.9	-0.1
	150	150.2	0.2
	180	179.5	-0.5

The root mean squares of the differences between reference angles and calculated angles of static, dynamic with statically hold, and dynamic with wavily hold were 0.28, 0.37, and 0.39 respectively.

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APPENDIX K
RESULTS OF PILOT STUDY

In the pilot study, ten male individuals with stroke and ten healthy subjects participated in the study. Characteristics of the subjects, correlations between clinical measures and gait performances in individuals with stroke, and comparisons of gait biomechanic characteristics between healthy and individuals with stroke were demonstrated.

K1. Characteristics of Subjects

Characteristics of ten male individuals with stroke and ten male healthy subjects are shown in Table K.1. There was no significant ($p>0.05$) difference in age (yr), body weight (kg), and height (cm) between two groups.

Table K.1 Comparisons of age, body weight, and height of the stroke (n=10) and the healthy (n=10)

Characteristics	Individuals with stroke (Mean±SD)	Control (Mean±SD)	p-value[a]
Age (yr)	52.1±8.67	51.6±9.03	0.901
Body weight (kg)	72.6±17.7	67.1±6.44	0.368
Height (cm)	168.4±4.86	169.6±3.13	0.520

Note: a = *p*-value from Unpaired t-test

Within ten individuals with stroke, there were four subjects affected in the right side and six affected in the left side. Three subjects were hemorrhagic stroke and seven were ischemic stroke.

Clinical examinations for ten individuals with stroke were composed of Thai Mental state Examination (TMSE) (see Appendix H), Modified Ashworth Scale

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(MAS) of five lower extremity muscle group which were hip adductors, hip extensors, ankle plantarflexors, ankle invertors, and knee extensors (see Appendix E), Fugl-Meyer Motor Assessment (FMA) of lower extremity (see Appendix F), Berg Balance Scale (BBS) which was classified into the scores of the affected and un-affected sides (see Appendices G and D), and gait speed at comfortable and fast speeds, as shown in Table K.2. TMSE score of all stroke subjects exhibited the acceptable range (more than 23 scores). MAS score of five lower extremity muscle group was ranged from 0-2 scores. FMA score was ranged from 16-33. BBS score was ranged from 44-54 for the affected side and 45-56 for the un-affected side. Comfortable gait speed was ranged from 0.39-0.88 m/s and fast gait speed was ranged from 0.55-1.36 m/s.

Table K.2 Clinical measures in individuals with stroke (n=10)

No	TMSE	MAS					FMA	BBS		Gait speed	
		HA	HE	KE	AP	AI		A	U	COM	FAST
1	27	0	0	0	0	0	33	53	54	0.62	0.80
2	29	0	0	0	1	1	30	54	56	0.79	0.95
3	29	1	1+	0	2	1+	16	48	51	0.39	0.55
4	29	1+	1+	1+	2	2	18	48	51	0.67	0.73
5	28	1+	1+	1+	2	1+	19	44	47	0.64	1.17
6	26	0	0	1	1	1	20	45	45	0.65	0.77
7	26	0	0	0	1	1	28	46	47	0.69	0.93
8	29	1	1	1	1	1	24	54	56	0.85	1.20
9	28	1	1	0	1+	1+	29	54	56	0.88	1.36
10	30	0	0	0	0	1	21	47	51	0.62	1.06

Note: TMSE = Thai Mental State Examination Scores
MAS = Modified Ashworth Scores
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
BBS = Berg Balance scores
A = Affected data
U = Un-affected data
FMA = Fugl-Meyer Motor Assessment (lower extremity)
COM = Comfortable gait speed
FAST = Fast gait speed

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K2. Correlations between Clinical Measures and Gait Performances

K2.1 Correlations between clinical measures and gait speeds

In this pilot study, clinical measures included muscle tone of five lower extremity muscle groups which was assessed by MAS. Lower extremity motor assessment was assessed by FMA and functional balance was assessed by BBS. The distribution of FMA score, BBS score, comfortable gait speed, and fast gait speed showed normal distribution in individuals with stroke subjects. Relationships of FMA and BBS scores to gait speeds, both comfortable and fast speeds, were conducted by Pearson's product moment correlation statistic. The relationship of MAS scores and two speeds of walking was tested by Spearman rank correlation statistic.

Table K.3 shows correlations between clinical measures and gait speeds at the comfortable and fast gait speeds of ten individuals with stroke. The results show no significant relationship in all correlations.

K2.2 Correlations between clinical measures and gait symmetries

Symmetrical gait variable was detected with the symmetrical indexes (SI). Six symmetrical gait variables contained the first (Z1) and second (Z2) peak vertical forces (%BW), single support time (s), step time (s), stance time (%GC), and swing time (%GC) at comfortable and fast gait speeds. Percentage of symmetrical index of each variable was calculated by the following equation;

$$SI = \frac{(V_{affected} - V_{un\text{-}affected})}{1/2\,(V_{affected} + V_{un\text{-}affected})} \times 100\% \qquad \text{equation 1}$$

After the six symmetrical gait variables were calculated, there was different function in the affected and un-affected sides in individuals with stroke. Positive and negative values of each symmetrical gait variable indicated motor function of these two sides. The positive sign represented that the value of the affected side was greater

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than that of the un-affected side. The negative sign represented that the values of the affected side was less than that of the un-affected side.

Table K.4 shows raw data and number of subjects showing symmetrical gait variables at the comfortable and fast speeds. It was found that all subjects with stroke showed consistency motor function of each side in the stance and the swing times both in the comfortable and fast speeds. The consistency characteristic was also found in the single support time at the comfortable speed. In the stance and the single support times, all individuals with stroke had longer stance time on the un-affected side than the affected side. In addition, the stroke showed longer swing time on the affected side than the un-affected side.

Inconsistency data of the Z1, Z2, and the step time at both comfortable and fast gait speeds as well as the single support time at fast gait speed of the affected and un-affected sides was showed.

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Table K.3 Correlations between clinical measures and gait speeds (n=10)

Clinical measures		Speeds	Correlation coefficient	*p*-value
MAS	HA	COM	$r_s = 0.099$	0.786
		FAST	$r_s = 0.099$	0.786
	HE	COM	$r_s = -0.066$	0.856
		FAST	$r_s = -0.066$	0.857
	KE	COM	$r_s = 0.083$	0.820
		FAST	$r_s = -0.028$	0.940
	AP	COM	$r_s = 0.057$	0.875
		FAST	$r_s = -0.172$	0.635
	AI	COM	$r_s = 0.079$	0.828
		FAST	$r_s = -0.085$	0.815
BBS	A	COM	$r_p = 0.568$	0.087
		FAST	$r_p = 0.308$	0.386
	U	COM	$r_p = 0.491$	0.149
		FAST	$r_p = 0.342$	0.334
FMA	-	COM	$r_p = 0.551$	0.099
		FAST	$r_p = 0.339$	0.337

Note: MAS = Modified Ashworth Scores
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
BBS = Berg Balance scores
FMA = Fugl-Meyer Motor Assessment (lower extremity)
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic
COM = Comfortable gait speed
FAST = Fast gait speed
A = Affected data
U = Un-affected data

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Table K.4 Raw data and number of subjects showing symmetrical variables at comfortable and fast gait speeds (n=10)

No	Z1		Z2		SST		Step time		Stance time		Swing time	
	COM	FAST	COM	FAST	COM	FAST	COM	FAST	COM	FAST	COM	FAST
1	64.76	-1142.74	573.50	185.78	-6.97	2.08	-6.39	-5.97	-3.00	-1.33	6.15	2.36
2	103.56	337.84	121.56	188.32	-6.71	-15.25	11.27	15.47	-4.74	-7.70	9.86	15.10
3	-287.57	901.37	-220.54	-482.16	-35.60	-41.47	5.67	23.29	-12.17	-17.43	33.83	42.08
4	1184.23	-62.16	-82.40	-19.10	-44.02	-34.86	29.95	28.57	-20.75	-15.32	40.77	27.72
5	669.78	425.98	-933.50	-1366.57	-21.26	-22.91	28.96	30.57	-14.50	-12.77	26.19	21.06
6	1049.40	-337.91	-713.23	-706.23	-26.54	-37.74	35.07	37.71	-15.67	-19.03	26.75	32.23
7	-286.13	395.57	-150.29	752.71	-18.39	-7.04	11.35	14.24	-7.00	-9.26	13.15	14.83
8	-435.87	-589.29	-666.54	-1389.18	-17.12	-14.31	9.71	18.01	-11.88	-15.09	19.85	21.50
9	-163.89	-539.97	105.38	647.90	0.00	-8.14	4.65	7.46	-2.92	-5.80	5.19	9.03
10	432.00	-457.56	-48.32	96.39	-15.56	-7.50	14.87	17.05	-7.23	-8.43	16.57	14.15
(+)	6	4	3	5	0	1	9	9	0	0	10	10
(-)	4	6	7	5	10	9	1	1	10	10	0	0

Note: COM = Comfortable gait speed
FAST = Fast gait speed
Z1 = 1st peak vertical force
Z2 = 2nd peak vertical force
SST = Single support time

The degree of relationship was determined in the variables that the number of subjects more than a half. Table K.5 presents the correlations between clinical measures and the Z1 and Z2. For the Z1 and clinical measures relationship, data from six subjects was determined the relationship both in the comfortable and fast speeds. Significant correlations were found between the Z1 and MAS of the knee extensors at the comfortable speed (r_s=0.833), between Z1 and MAS of the ankle invertors at the comfortable speed (r_s=0.820), and between Z1 and FMA both in the comfortable (r_p=-0.870) and fast gait speeds (r_p=-0.907). For the Z2, only the comfortable speed was determined and there was no significant relationship between Z2 and the clinical measures.

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Table K.5 Correlations between clinical measures and the first (Z1) and second peak vertical (Z2) forces

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
The first peak vertical force	MAS	HA	COM	$r_s = 0.621$	6	The second peak vertical force	MAS	HA	COM	$r_s = -0.265$	7
			FAST	$r_s = 0.309$	6				FAST	n/a	5
		HE	COM	$r_s = 0.621$	6			HE	COM	$r_s = -0.231$	7
			FAST	$r_s = 0.309$	6				FAST	n/a	5
		KE	COM	$r_s = 0.833$*	6			KE	COM	$r_s = -0.454$	7
			FAST	$r_s = 0.617$	6				FAST	n/a	5
		AP	COM	$r_s = 0.717$	6			AP	COM	$r_s = -0.347$	7
			FAST	$r_s = 0.559$	6				FAST	n/a	5
		AI	COM	$r_s = 0.820$*	6			AI	COM	$r_s = 0.000$	7
			FAST	$r_s = 0.698$	6				FAST	n/a	5
	BBS	A	COM	$r_p = -0.726$	6		BBS	A	COM	$r_p = 0.087$	7
			FAST	$r_p = -0.596$	6				FAST	n/a	5
		U	COM	$r_p = -0.730$	6			U	COM	$r_p = 0.209$	7
			FAST	$r_p = -0.455$	6				FAST	n/a	5
	FMA	-	COM	$r_p = -0.870$*	6		FMA	-	COM	$r_p = 0.055$	7
			FAST	$r_p = -0.907$*	6				FAST	n/a	5

Note: r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic
*= Significant difference at p-value<0.05
MAS = Modified Ashworth Scores
BBS = Berg Balance Scores
FMA = Fugl-Meyer Assessment (lower extremity motor function)
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
A = Affected data
U = Un-affected data
COM = Comfortable gait speed
FAST = Fast gait speed
n/a = not assessment

Table K.6 presents correlation between clinical measures and single support and step times. Ten individuals with stroke were determined the relationships of single support time and clinical measures for the comfortable and nine for the fast speeds. Significant relationships were found between the single support time and FMA both in the comfortable and fast speeds (r_p=0.840 and r_p=0.775). There were significant

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relationships between step time and MAS of knee extensors at the fast speed (r_s=0.765), between step time and BBS of the affected data at the fast speed (r_p=-0.677), between step time and BBS of the un-affected data at the comfortable and fast speeds (r_p=-0.671, r_p=-0.695), and between step time and FMA at the fast speed (r_p=-0.745).

Table K.6 Correlations between clinical measures and symmetrical variables (single support and step times)

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
Single support time	MAS	HA	COM	$r_s = -0.436$	10	Step time	MAS	HA	COM	$r_s = -0.027$	9
			FAST	$r_s = -0.353$	9				FAST	$r_s = 0.347$	9
		HE	COM	$r_s = -0.521$	10			HE	COM	$r_s = -0.125$	9
			FAST	$r_s = -0.501$	9				FAST	$r_s = 0.374$	9
		KE	COM	$r_s = -0.607$	10			KE	COM	$r_s = 0.639$	9
			FAST	$r_s = -0.435$	9				FAST	$r_s = 0.765$*	9
		AP	COM	$r_s = -0.574$	10			AP	COM	$r_s = -0.062$	9
			FAST	$r_s = -0.561$	9				FAST	$r_s = 0.346$	9
		AI	COM	$r_s = -0.500$	10			AI	COM	$r_s = -0.037$	9
			FAST	$r_s = -0.412$	9				FAST	$r_s = 0.224$	9
	BBS	A	COM	$r_p = 0.589$	10		BBS	A	COM	$r_p = -0.647$	9
			FAST	$r_p = 0.392$	9				FAST	$r_p = -0.677$*	9
		U	COM	$r_p = 0.511$	10			U	COM	$r_p = -0.671$*	9
			FAST	$r_p = 0.396$	9				FAST	$r_p = -0.695$*	9
	FMA	-	COM	$r_p = 0.840$*	10		FMA	-	COM	$r_p = -0.507$	9
			FAST	$r_p = 0.775$*	9				FAST	$r_p = -0.745$*	9

Note: r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic
*= Significant difference at *p*-value<0.05
MAS = Modified Ashworth Scores
BBS = Berg Balance Scores
FMA = Fugl-Meyer Assessment (lower extremity motor function)
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
A = Affected data
U = Un-affected data
COM = Comfortable gait speed
FAST = Fast gait speed

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The relationship between clinical measures and stance time as well as swing time were determined in all strokes as shown in Table K.7. For the stance time, there were significant relationships with the MAS of knee extensors at the comfortable speed (r_s=-0.833) and FMA both in the comfortable and fast speeds (r_p=0.821 and r_p=0.833). For the swing time, there were significant relationships with the MAS of knee extensors at the comfortable speed (r_s=0.661) and with the FMA both in the comfortable and fast speeds (r_p=-0.911 and r_p=-0.856).

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Table K.7 Correlations between clinical measures and symmetrical variables (stance and swing times)

Variable	Clinical measure		Speed	Correlation coefficient	Number of subject	Variable	Clinical measure		Speed	Correlation coefficient	Number of subject
Stance time	MAS	HA	COM	r_s = -0.498	10	**Swing time**	MAS	HA	COM	r_s = 0.487	10
			FAST	r_s = -0.321	10				FAST	r_s = 0.389	10
		HE	COM	r_s = -0.498	10			HE	COM	r_s = 0.566	10
			FAST	r_s = -0.407	10				FAST	r_s = 0.502	10
		KE	COM	r_s = -0.833*	10			KE	COM	r_s = 0.661*	10
			FAST	r_s = -0.568	10				FAST	r_s = 0.525	10
		AP	COM	r_s = -0.526	10			AP	COM	r_s = 0.553	10
			FAST	r_s = -0.483	10				FAST	r_s = 0.587	10
		AI	COM	r_s = -0.490	10			AI	COM	r_s = 0.518	10
			FAST	r_s = -0.363	10				FAST	r_s = 0.454	10
	BBS	A	COM	r_p = 0.570	10		BBS	A	COM	r_p = -0.566	10
			FAST	r_p = 0.493	10				FAST	r_p = -0.467	10
		U	COM	r_p = 0.517	10			U	COM	r_p = -0.463	10
			FAST	r_p = 0.477	10				FAST	r_p = -0.419	10
	FMA	-	COM	r_p = 0.821*	10		FMA	-	COM	r_p = -0.911*	10
			FAST	r_p = 0.833*	10				FAST	r_p = -0.856*	10

Note: r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic
*= Significant difference at *p*-value<0.05
MAS = Modified Ashworth Scores
BBS = Berg Balance Scores
FMA = Fugl-Meyer Assessment (lower extremity motor function)
HA = Hip adductors
HE = Hip extensors
KE = Knee extensors
AP = Ankle plantarflexors
AI = Ankle invertors
A = Affected data
U = Un-affected data
COM = Comfortable gait speed
FAST = Fast gait speed

K3. Comparisons of Gait Biomechanic Characteristics between Healthy and Individuals with Stroke

Prior to compare the data, all variables were checked for the distribution with Kolmogorov Smirnov Goodness of Fit test, and all variables showed normal distribution.

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K3.1 Temporo-spatial data

Temporo-spatial data in this study were divided into two parts. The first comparison was the analysis between the healthy and the stroke. It composed of cadence (steps/min), double support time (s), step width (m), stride length (m), stride time (s), and gait speed (m/s). There were significant differences in all variables between the healthy and the stroke for both the comfortable and fast speeds, as shown in Table K.8. Cadence, stride length, and gait speed both in the comfortable and fast speeds of individuals with stroke significantly showed less than those of normal healthy. In addition, double support time, step width, and stride time of individuals with stroke significantly showed greater than those of normal healthy.

The second comparison: single support time (s), step length (m), and step time (s) were analyzed between the healthy and the affected, between the healthy and the un-affected, and between the affected and the un-affected sides, as shown in Table K.9. For the comparisons between the control and the un-affected sides of the stroke, it was found that there was significant difference in the single support time and the step length at both the comfortable and fast gait speeds. In addition, there was significant difference in the step time only in the comfortable speed, not in the fast speed. For the comparisons between the healthy and the affected, significant differences were found in the step length and step time in both gait speeds. For the comparisons between the affected and the un-affected sides of the stroke, significant differences were found in the single support and step times in both gait speeds.

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Table K.8 Comparisons of cadence (steps/min), double support time (s), step width (m), stride length (m) and time (s), and gait speed (m/s) between the stroke (n=10) and the healthy (n=10) in the comfortable and fast gait speeds

Variables	Speeds	Stroke (Mean±SD)	Control (Mean±SD)	*p*-values[a]
Cadence (steps/min)	COM	88.79±12.23	107.77±6.47	0.001*
	FAST	105.26±15.37	127.23±6.15	0.001*
Double support time (s)	COM	0.47±0.17	0.30±0.04	0.006*
	FAST	0.34±0.13	0.20±0.03	0.010*
Step width (m)	COM	0.24±0.05	0.18±0.02	0.003*
	FAST	0.24±0.05	0.18±0.02	0.002*
Stride length (m)	COM	0.89±0.09	1.25±0.09	0.001*
	FAST	1.06±0.17	1.49±0.16	0.001*
Stride time (s)	COM	1.39±0.23	1.12±0.07	0.002*
	FAST	1.17±0.20	0.95±0.05	0.005*
Gait speed (m/s)	COM	0.68±0.14	1.14±0.13	0.001*
	FAST	0.95±0.25	1.59±0.20	0.001*

Note: a= *p*-value from Unpaired t-test
*= Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed

Table K.9 Comparisons of single support time (s), step length (m), and step time (s) between groups (the healthy and the stroke) (n=10) and within group (affected and un-affected sides) (n=10)

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
SST (s)	COM	0.41±0.02	0.50±0.06	0.41±0.03	0.001*	0.919	0.003*
	FAST	0.37±0.02	0.45±0.06	0.38±0.05	0.003*	0.953	0.005*
Step length (m)	COM	0.63±0.04	0.46±0.07	0.44±0.06	0.000*	0.000*	0.459
	FAST	0.75±0.07	0.53±0.10	0.53±0.10	0.000*	0.000*	1.000
Step T (s)	COM	0.56±0.04	0.65±0.12	0.75±0.12	0.043*	0.001*	0.006*
	FAST	0.47±0.03	0.53±0.09	0.64±0.11	0.083	0.001*	0.001*

Note: SST = Single support time (s)
a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides
* = Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed

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K 3.2 Kinematic data of hip, knee and ankle

K 3.2.1 Angular displacement (degrees)

The angular displacements of the hip, knee, and ankle in ten normal healthy and stroke at comfortable and fast gait speeds were showed in Figure K.1-6. In the angular displacement graphs, the X-axis presents the consumed time during one gait cycle which is expressed in frames and the Y-axis presents the angle which is expressed in degrees. In the sagittal plane, the positive value represents the flexion of hip and knee joints and dorsiflexion of ankle joint. The negative value represents the extension of hip and knee joints and plantarflexion of ankle joint. In the frontal plane, the positive value represents the abduction of hip, knee, and ankle joints. The negative value represents the adduction of hip, knee, and ankle joints. In the transverse plane, the positive value represents the internal rotation of hip, knee, and ankle joints. The negative value represents the external rotation of the hip, knee, and ankle joints.

The angular displacement patterns of the hip, knee, and ankle joints in normal healthy showed smoother than those of stroke. Time consumption during one gait cycle in healthy was less than those of the stroke as shown the less frames consumed both in the comfortable and fast gait speeds in the healthy.

Figures K.1 and K.2 present the angular displacements of the hip in the sagittal, frontal, and transverse planes of normal healthy and individuals with stroke subjects. More angular movement of some subjects with stroke was found in the frontal and transverse planes.

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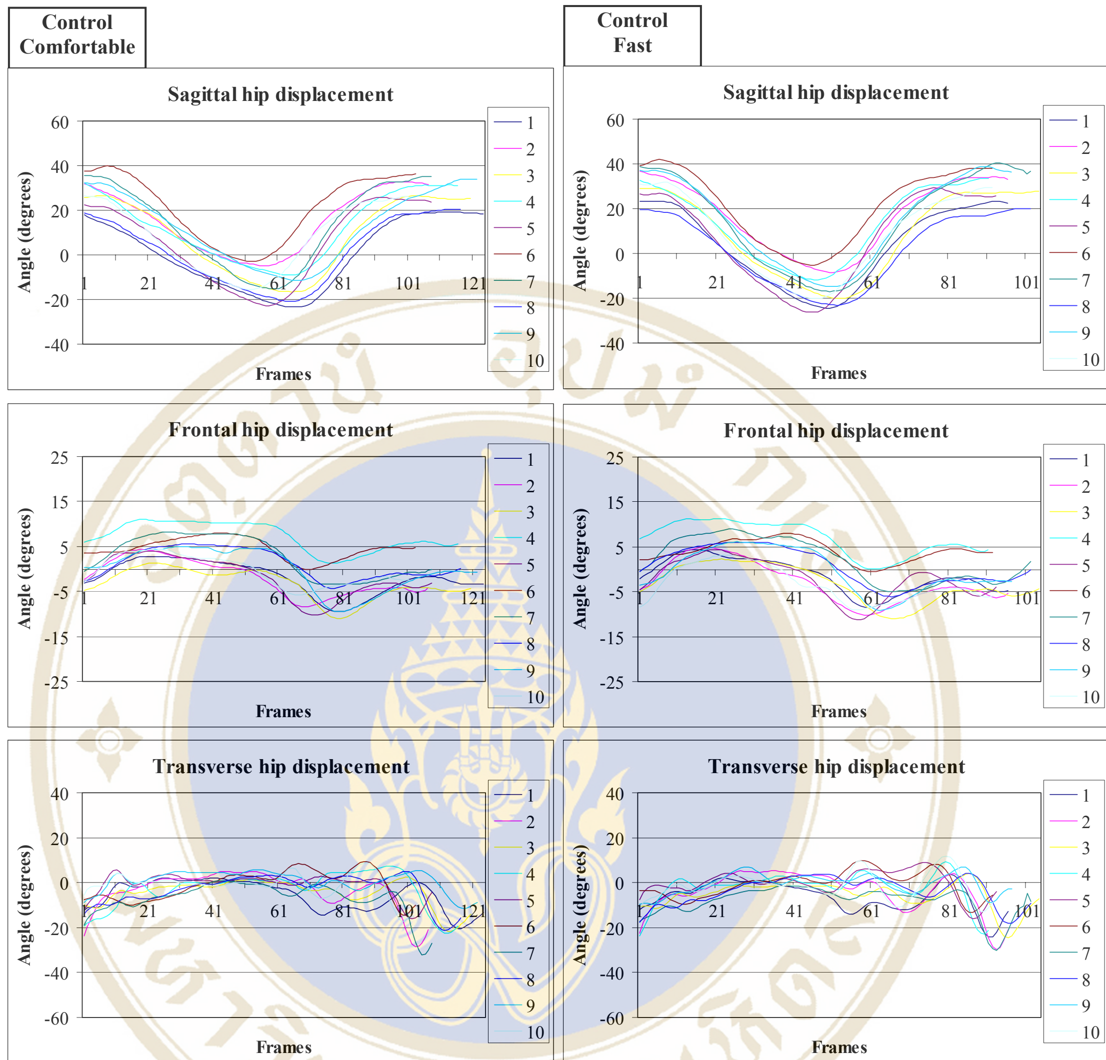

Figure K.1 Hip displacements in the sagittal, frontal, and transverse planes of normal healthy at comfortable and fast gait speeds.

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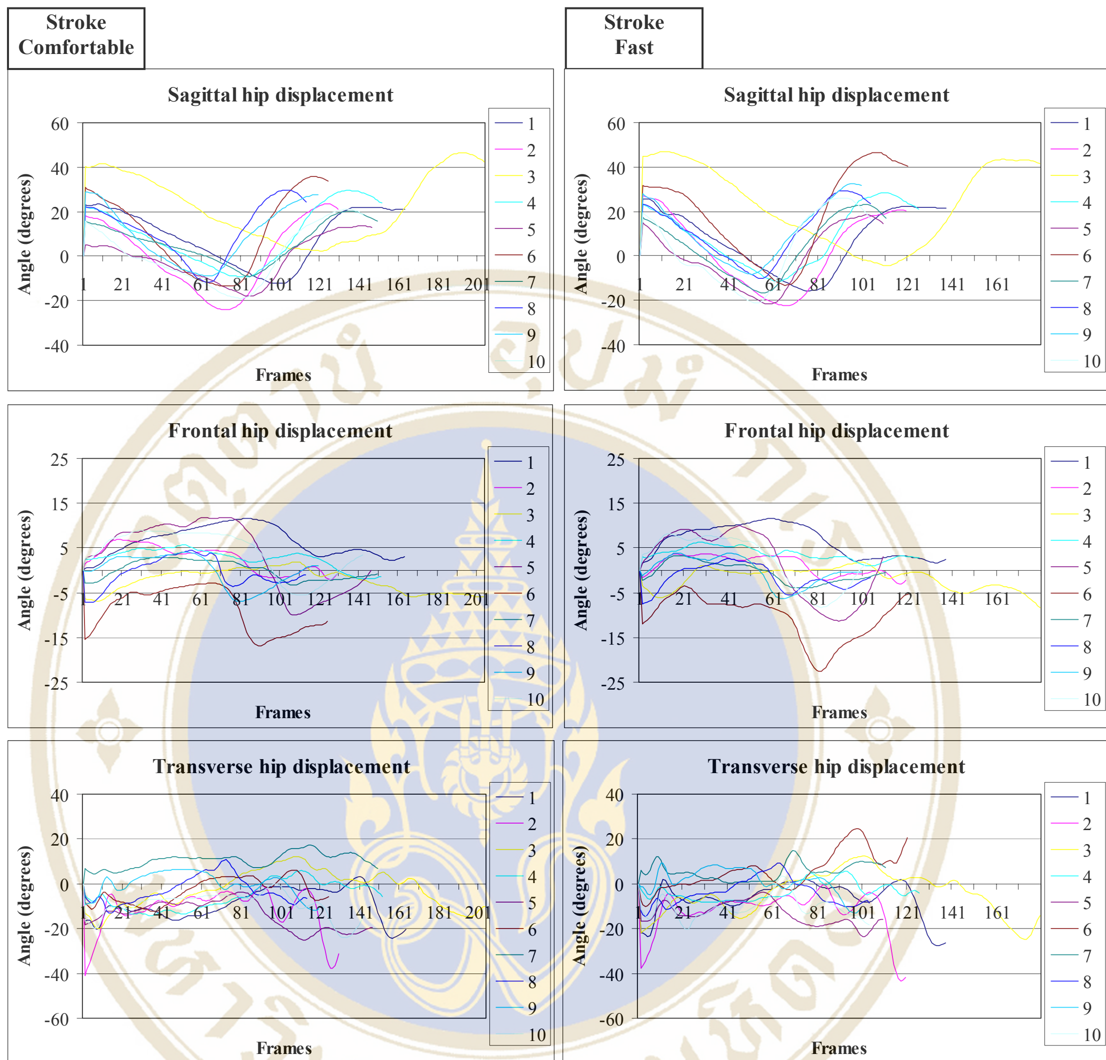

Figure K.2 Hip displacements in the sagittal, frontal, and transverse planes of individuals with stroke at comfortable and fast gait speeds.

Figures K.3 and K.4 present the angular displacements of the knee in the sagittal, frontal, and transverse planes of normal healthy and individuals with stroke subjects. In the sagittal plane, it was showed the double knee flexion curves in normal healthy both in the comfortable and fast gait speeds. Slightly knee flexion was occurred at the early stance phase of gait in normal. In contrast, some stroke subjects showed loss of normal knee pattern and showed knee hyperextension during loading response event instead. For the knee angular displacement in the frontal and transverse planes, the stroke showed more movement of the knee than the healthy.

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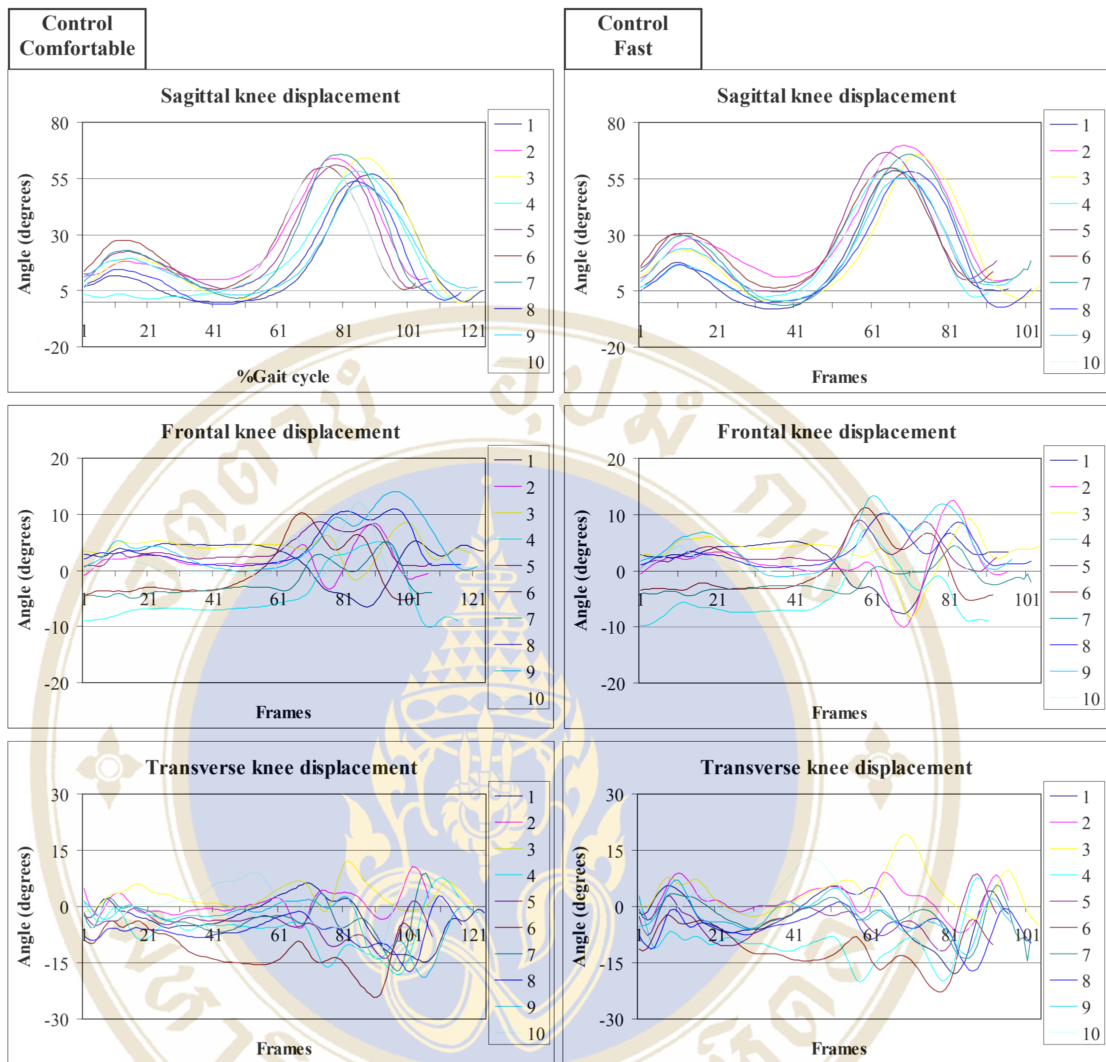

Figure K.3 Knee displacements in the sagittal, frontal, and transverse planes of normal healthy at comfortable and fast gait speeds.

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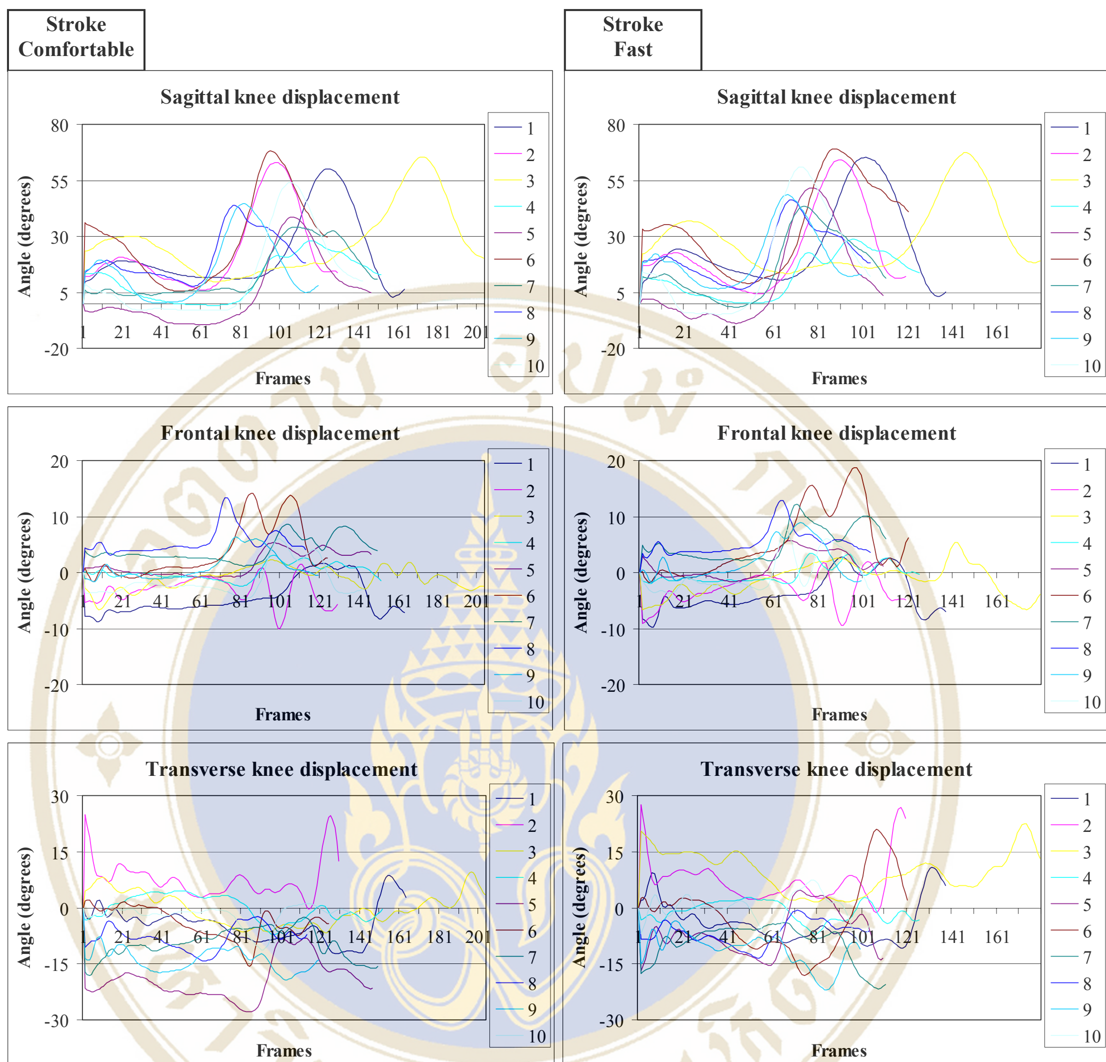

Figure K.4 Knee displacements in the sagittal, frontal, and transverse planes of individuals with stroke at comfortable and fast gait speeds.

Figures K.5 and K.6 present the angular displacements of the ankle in the sagittal, frontal, and transverse planes of normal healthy and individuals with stroke subjects. In the sagittal plane, lesser ankle plantarflexion were found in the stroke. For the frontal and transverse planes, large variability pattern were found in individuals with stroke.

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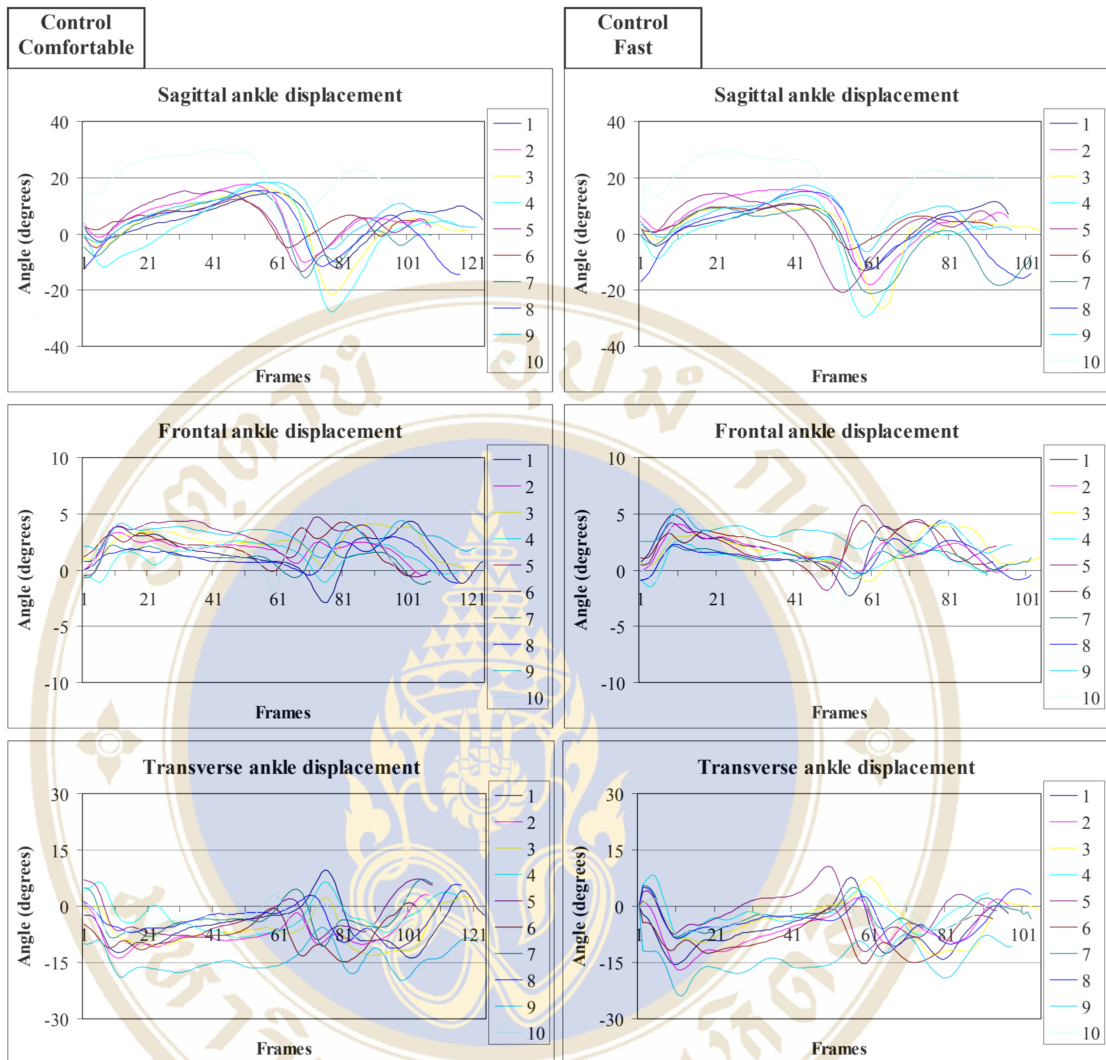

Figure K.5 Ankle displacements in the sagittal, frontal, and transverse planes of normal healthy at comfortable and fast gait speeds.

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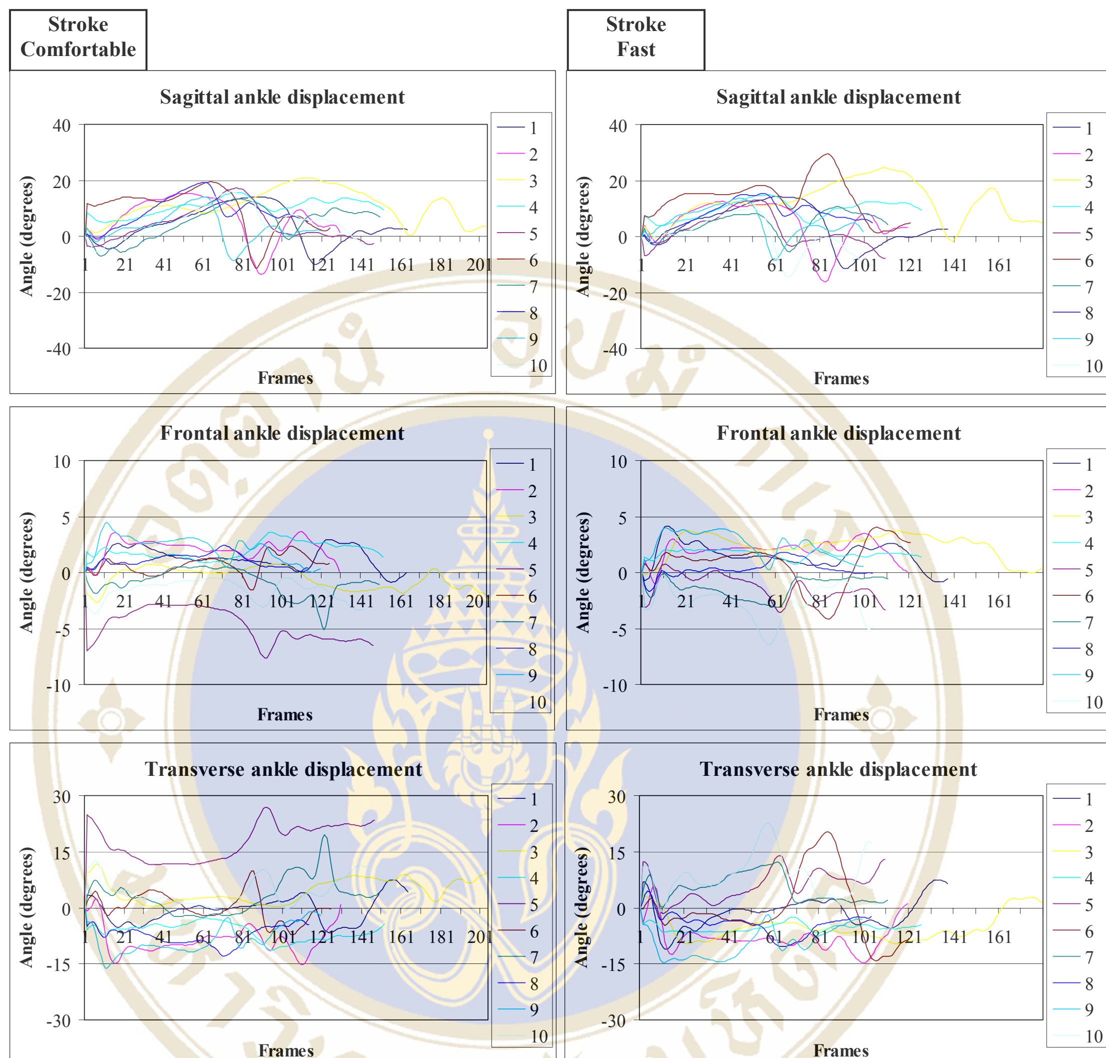

Figure K.6 Ankle displacements in the sagittal, frontal, and transverse planes of individuals with stroke at comfortable and fast gait speeds.

Number of subjects showing angular displacement of hip, knee, and ankle in the sagittal, frontal, and transverse planes during initial contact (IC), midstance (MS), and toe off (TO) events at comfortable and fast gait speeds is presented in Tables K.10 and K.11, respectively. The positive and negative signs represent the direction of muscle group action corresponding to the plane of movement. In the sagittal plane, positive sign represents flexion of the hip and knee joints and dorsiflexion of the ankle joint and negative sign represents extension of the hip and knee joints and plantarflexion of the ankle joint. In the frontal plane, positive sign represents abduction and negative sign represents adduction of all joints. In the

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transverse plane, positive sign represents internal rotation and negative sign represents external rotation of all joints. Angular displacements of the hip, knee, and ankle are compared at the initial contact (IC), midstance (MS), and toe off (TO) events in three planes of movements as shown in Tables K.12 and K.13.

Table K.12 shows the comparisons of the angular displacements of the hip, knee, and ankle between the healthy and the stroke and between the affected and un-affected sides of the stroke at the comfortable gait speed. There were significant differences in the knee and ankle at the toe off between the healthy and the un-affected side in the sagittal plane. For the frontal plane, there was significant in the ankle at the midstance between the healthy and the stroke. In addition, there was significant difference in the hip at the midstance between the healthy and the stroke in the transverse plane. The comparisons of the angular displacement of the hip, knee, and ankle between the healthy and the affected side of the stroke showed that there were significant differences in the knee and ankle in the sagittal plane at the toe off. In addition, the ankle in the frontal plane was significant difference at the toe off. In the transverse plane, significant differences were shown in the hip at the midstance and the ankle at the toe off. The comparisons of angular displacement of the hip, knee, and ankle between the un-affected and affected sides showed that there was significant difference of the knee in the sagittal plane at the toe off.

Table K.13 shows the comparisons of the angular displacements of the hip, knee, and ankle between the healthy and the stroke and between the affected an un-affected sides of the stroke at the fast gait speed. There was significant difference in the ankle at the midstance between the healthy and the un-affected side of the stroke in the frontal plane. Significant difference was shown in the hip at the midstance in the transverse plane. The comparisons of the angular displacement of the hip, knee, and ankle between the healthy and the affected side of the stroke showed that there were significant differences in the sagittal plane for the hip at the initial contact, in the frontal plane for the ankle at the initial contact, in the frontal plane for the ankle at toe off, in the transverse plane for the hip at the midstance, in the transverse plane for the ankle at the initial contact and toe off. The comparisons of the

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angular displacement of the hip, knee, and ankle between the un-affected and affected sides of the stroke showed that there was significant difference in the sagittal plane for the hip and ankle at the initial contact.

Table K.10 Number of subjects showing angular displacement of hip, knee, and ankle in the sagittal, frontal, and transverse planes at comfortable gait speed

Plane	Joint	Action	IC Number of subject			MS Number of subject			TO Number of subject		
			C	A	U	C	A	U	C	A	U
Sagittal	**Hip**	F (+)	10	10	10	8	7	8	2	3	3
		E (-)	0	0	0	2	3	2	8	7	7
	Knee	F (+)	10	8	10	10	7	10	10	10	10
		E (-)	0	2	0	0	3	0	0	0	0
	Ankle	DF (+)	4	6	9	10	9	10	0	7	1
		PF (-)	6	4	1	0	1	0	10	3	9
Frontal	**Hip**	AB (+)	3	6	4	10	9	6	1	2	1
		AD (-)	7	4	6	0	1	4	9	8	9
	Knee	AB (+)	6	5	3	6	4	4	9	10	9
		AD (-)	4	5	7	4	6	6	1	0	1
	Ankle	AB (+)	9	5	6	10	8	8	7	6	7
		AD (-)	1	5	4	0	2	2	3	4	3
Transverse	**Hip**	IR (+)	0	2	2	6	5	4	8	6	7
		ER (-)	10	8	8	4	5	6	2	4	3
	Knee	IR (+)	1	2	4	1	2	3	0	0	1
		ER (-)	9	8	6	9	8	7	10	10	9
	Ankle	IR (+)	2	6	5	10	3	2	3	4	5
		ER (-)	8	4	5	0	7	8	7	6	5

Note: IC = Initial contact event
MS = Midstance event
TO = Toe off event
DF (+) = Dorsiflexion
PF (-) = Plantarflexion
F (+) = Flexion
E (-) = Extension
IR (+) = Internal rotation
ER (-) = External rotation
A = Affected side
U = Un-affected side
C = Control

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Table K.11 Number of subjects showing angular displacement of hip, knee, and ankle in the sagittal, frontal, and transverse planes at fast gait speed

Plane	Joint	Action	IC			MS			TO		
			Number of subject			Number of subject			Number of subject		
			C	A	U	C	A	U	C	A	U
Sagittal	Hip	F (+)	10	10	10	5	6	8	1	2	3
		E (-)	0	0	0	5	4	2	9	8	7
	Knee	F (+)	10	10	10	10	7	10	0	0	0
		E (-)	0	0	0	0	3	0	10	10	10
	Ankle	DF (+)	7	5	9	10	10	10	0	6	2
		PF (-)	3	5	1	0	0	0	10	4	8
Frontal	Hip	AB (+)	2	5	3	10	9	5	1	2	2
		AD (-)	8	5	7	0	1	5	9	8	8
	Knee	AB (+)	5	7	3	6	5	3	9	9	8
		AD (-)	5	3	7	4	5	7	1	1	2
	Ankle	AB (+)	9	4	7	10	8	8	8	6	7
		AD (-)	1	6	3	0	2	2	2	4	3
Transverse	Hip	IR (+)	0	0	1	8	4	4	8	6	6
		ER (-)	10	10	9	2	6	6	2	4	4
	Knee	IR (+)	2	1	4	0	2	3	2	1	3
		ER (-)	8	9	6	10	8	7	8	9	7
	Ankle	IR (+)	3	6	4	0	3	2	4	4	3
		ER (-)	7	4	6	10	7	8	6	6	7

Note: IC = Initial contact event
MS = Midstance event
TO = Toe off event
DF (+) = Dorsiflexion
PF (-) = Plantarflexion
F (+) = Flexion
E (-) = Extension
IR (+) = Internal rotation
ER (-) = External rotation
A = Affected side
U = Un-affected side
C = Control

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Table K.12 Comparisons of angular displacements (degrees) of hip, knee, and ankle between groups (the healthy and the stroke) (n=10) and within group (affected and un-affected sides) at comfortable gait speed (n=10)

Variable			Control	Un-affected	Affected	*p*-	*p*-	*p*-
Plane	**Joint**	**Event**	**(Mean±SD)**	**(Mean±SD)**	**(Mean±SD)**	**values[a]**	**values[a]**	**values[a]**
Sagittal	**Hip**	**IC**	26.72±5.70	27.05±7.35	20.77±7.66	0.911	0.065	0.049
		MS	5.23±4.54	6.22±5.58	6.88±6.67	0.667	0.525	0.682
		TO	7.55±4.33	5.42±7.21	4.70±4.01	0.434	0.143	0.778
	Knee	**IC**	7.71±2.22	13.08±8.77	12.94±9.24	0.089	0.112	0.978
		MS	7.91±3.65	7.84±3.30	10.74±7.80	0.966	0.318	0.193
		TO	39.38±3.93	45.96±3.81	31.21±10.00	0.001*	0.034*	0.004*
	Ankle	**IC**	3.94±5.18	3.92±5.17	4.94±2.74	0.991	0.598	0.615
		MS	9.44±5.48	8.32±2.51	7.39±5.35	0.566	0.409	0.637
		TO	12.25±5.23	7.41±2.97	5.99±2.88	0.020*	0.004*	0.394
Frontal	**Hip**	**IC**	2.40±1.71	3.74±4.24	3.37±4.25	0.371	0.512	0.845
		MS	4.84±2.34	2.92±2.72	4.97±2.94	0.108	0.915	0.113
		TO	4.98±3.04	5.22±4.21	4.32±4.21	0.884	0.695	0.670
	Knee	**IC**	2.58±1.99	3.75±2.57	2.65±2.55	0.268	0.949	0.264
		MS	2.99±1.23	2.97±2.27	2.43±2.32	0.980	0.507	0.627
		TO	6.35±3.75	6.81±4.80	6.20±4.08	0.811	0.932	0.618
	Ankle	**IC**	0.93±0.49	1.20±1.05	1.68±1.86	0.483	0.244	0.554
		MS	2.71±0.50	1.64±0.83	2.22±1.62	0.003*	0.373	0.402
		TO	0.98±0.51	1.42±1.09	2.53±1.73	0.260	0.021*	0.166
Transverse	**Hip**	**IC**	9.27±3.70	14.41±10.37	8.49±6.01	0.167	0.733	0.197
		MS	3.08±1.79	7.99±5.12	7.09±3.60	0.010*	0.006*	0.653
		TO	5.46±2.57	7.95±6.60	5.33±4.58	0.290	0.938	0.253
	Knee	**IC**	5.15±3.36	11.02±11.63	8.91±7.11	0.154	0.155	0.612
		MS	6.35±2.52	8.15±9.06	8.66±6.48	0.558	0.315	0.876
		TO	6.96±3.86	8.43±7.33	9.90±6.24	0.583	0.223	0.615
	Ankle	**IC**	3.01±2.51	4.90±4.41	6.54±6.24	0.255	0.114	0.565
		MS	8.38±3.12	6.42±3.69	7.86±5.84	0.216	0.806	0.591
		TO	4.28±1.50	5.91±4.32	9.62±5.41	0.283	0.013*	0.181

Note: a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides
* = Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed
IC = Initial contact event
MS = Midstance event
TO = Toe off event

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Table K.13 Comparisons of angular displacements (degrees) of hip, knee, and ankle between groups (the healthy and the stroke) (n=10) and within group (affected and un-affected sides) at fast gait speed (n=10)

Variable			Control	Un-affected	Affected	*p*-	*p*-	*p*-
Plane	**Joint**	**Event**	**(Mean±SD)**	**(Mean±SD)**	**(Mean±SD)**	**values[a]**	**values[a]**	**values[a]**
Sagittal	**Hip**	**IC**	30.57±4.60	29.30±6.93	22.54±5.73	0.635	0.003*	0.020*
		MS	3.80±3.82	7.40±5.75	6.34±5.13	0.116	0.224	0.616
		TO	9.52±5.38	7.72±5.16	7.07±4.60	0.456	0.290	0.760
	Knee	**IC**	10.16±3.23	13.91±10.19	13.97±9.60	0.291	0.250	0.991
		MS	8.02±3.70	9.87±5.03	10.30±7.08	0.363	0.384	0.868
		TO	39.25±3.87	42.85±12.68	33.02±11.08	0.402	0.111	0.123
	Ankle	**IC**	5.56±5.27	2.95±2.88	5.30±2.79	0.187	0.892	0.049*
		MS	10.67±6.11	9.26±3.45	7.99±4.88	0.534	0.294	0.467
		TO	15.37±5.27	10.86±7.47	8.30±7.13	0.136	0.021	0.499
Frontal	**Hip**	**IC**	3.60±1.88	3.63±3.63	4.36±3.59	0.985	0.564	0.651
		MS	4.98±2.30	2.91±3.05	4.57±2.91	0.103	0.733	0.255
		TO	5.80±3.09	5.48±4.52	4.68±4.46	0.853	0.523	0.698
	Knee	**IC**	2.50±2.30	4.52±3.09	2.50±2.29	0.115	0.995	0.092
		MS	2.76±1.10	3.33±1.92	2.29±1.83	0.426	0.491	0.292
		TO	5.79±3.88	7.14±5.30	5.72±4.29	0.525	0.972	0.323
	Ankle	**IC**	0.85±0.60	1.27±0.71	1.60±0.89	0.171	0.040*	0.375
		MS	2.85±0.51	1.86±1.28	2.16±1.95	0.035*	0.307	0.713
		TO	1.08±0.68	2.02±1.27	2.32±1.38	0.057	0.023*	0.650
Transverse	**Hip**	**IC**	9.67±4.70	15.01±10.16	9.60±6.29	0.156	0.979	0.213
		MS	3.85±2.25	8.64±5.37	7.73±5.08	0.018*	0.047*	0.648
		TO	4.19±2.04	7.49±6.85	4.98±4.51	0.173	0.619	0.245
	Knee	**IC**	5.66±3.72	11.89±12.17	7.58±5.91	0.151	0.396	0.334
		MS	7.33±2.50	8.45±7.51	5.73±4.31	0.662	0.328	0.351
		TO	5.92±4.01	11.18±7.97	7.75±4.68	0.078	0.359	0.195
	Ankle	**IC**	2.83±2.28	4.86±2.97	5.67±3.50	0.103	0.045*	0.627
		MS	8.38±3.00	6.42±5.14	7.74±6.53	0.311	0.784	0.677
		TO	4.03±2.73	7.47±5.72	9.14±4.85	0.110	0.010*	0.474

Note: a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides
* = Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed
IC = Initial contact event
MS = Midstance event
TO = Toe off event

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K 3.2.2 Angular velocity (degrees/s)

Five peak angular velocities were compared during the swing phase which were composed of ankle velocity during the initial swing (A1) and the midswing (A2), hip velocity during the initial swing (H) and knee velocity during the initial swing (K1) and the terminal swing (K2) periods. The angular velocity of the hip, knee, and ankle in the sagittal plane of ten normal healthy and the individuals with stroke were shown in Figures K.7 and K.8. In the angular velocity graphs, the X-axis presents the frames and the Y-axis presents the velocity (degrees/s). In the sagittal plane, the positive value represents the velocities of the hip and knee flexion and ankle dorsiflexion. The negative value represents the velocities of the hip extension, knee extension and ankle plantarflexion. Patterns of angular velocity of all joints in the healthy were smoother than the stroke both in the comfortable and fast gait speeds.

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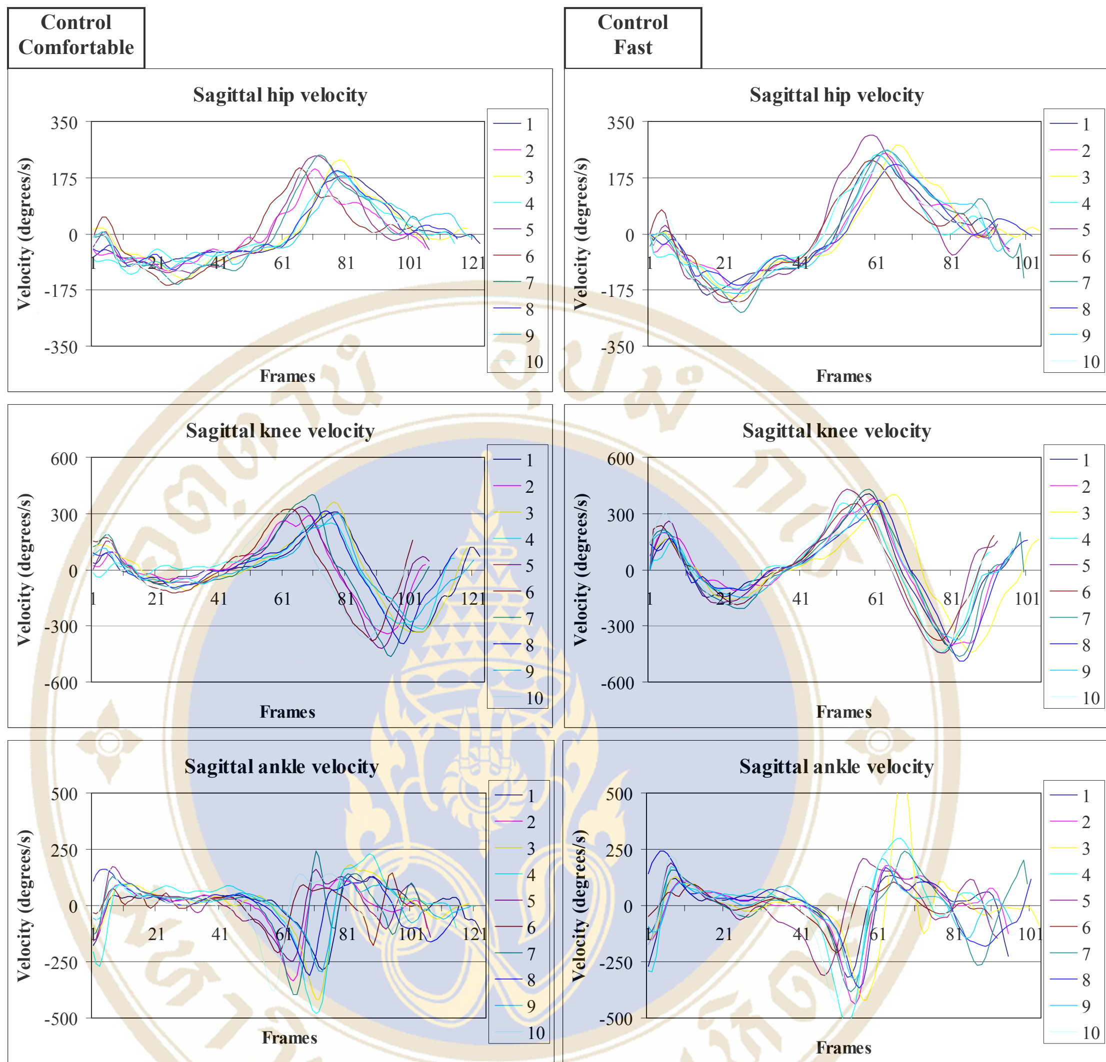

Figure K.7 Angular velocities in the sagittal plane of normal healthy at comfortable and fast gait speeds.

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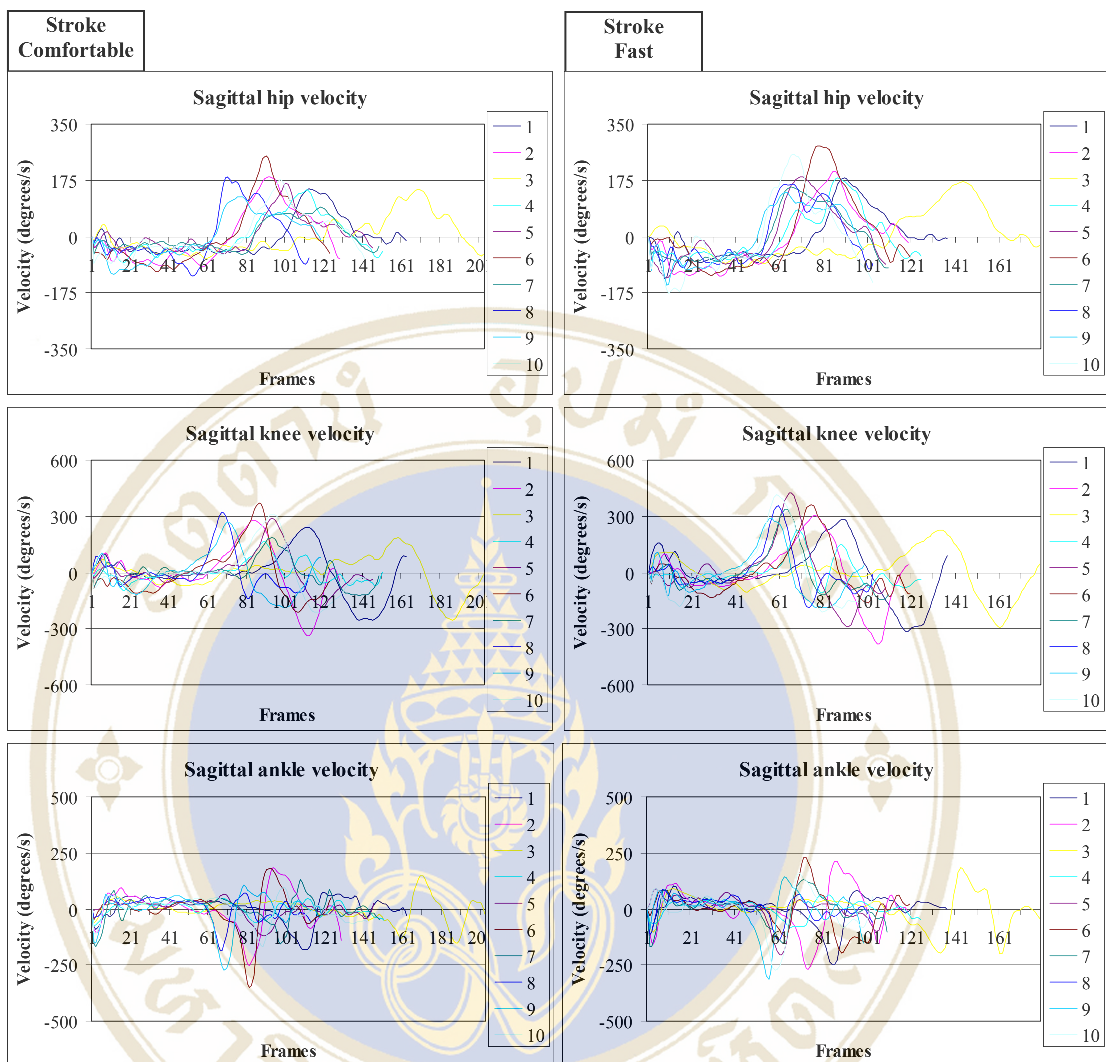

Figure K.8 Angular velocities in the sagittal plane of individuals with stroke at comfortable and fast gait speeds.

Table K.14 presents the number of subjects showing peak angular velocity of the hip, knee, and ankle in the sagittal plane. Both the healthy and the stroke groups showed consistency data. One of individuals with stroke showed inconsistency in only the ankle velocity during midswing (A2) both in the comfortable and fast gait speeds. The positive sign represents flexion of the hip and knee joints and dorsiflexion of the ankle joint and negative sign represents extension of the hip and knee joints and plantarflexion of the ankle joint.

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The absolute values of peak angular velocity of the hip, knee, and ankle in the sagittal plane were used to compare between individuals with stroke and healthy groups as well as between the affected and the un-affected sides of individuals with stroke as shown in Table K.15. Peak angular velocity between the healthy and the un-affected side of the stroke showed significant differences in the hip and ankle joints both in the comfortable and fast speeds. The comparisons between the healthy and the affected sides of the stroke showed significant differences in peak angular velocity in all joints at both gait speeds except the knee joint at fast gait speed. There was a significant difference of peak angular velocity in all joints at both gait speeds except the knee joint in both speeds between the un-affected and affected sides of the stroke.

Table K.14 Number of subjects showing peak angular velocity of hip, knee, and ankle in the sagittal plane at comfortable and fast gait speed

Comfortable gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
H	**C**	**A**	**U**	**K1**	**C**	**A**	**U**	**A1**	**C**	**A**	**U**
F (+)	10	10	10	F (+)	10	10	10	DF (+)	0	0	0
E (-)	0	0	0	E (-)	0	0	0	PF (-)	10	10	10
				K2	**C**	**A**	**U**	**A2**	**C**	**A**	**U**
				F (+)	0	0	0	DF (+)	10	9	10
				E (-)	10	10	10	PF (-)	0	1	0
Fast gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
H	**C**	**A**	**U**	**K1**	**C**	**A**	**U**	**A1**	**C**	**A**	**U**
F (+)	10	10	10	F (+)	10	10	10	DF (+)	0	0	0
E (-)	0	0	0	E (-)	0	0	0	PF (-)	10	10	10
				K2	**C**	**A**	**U**	**A2**	**C**	**A**	**U**
				F (+)	0	0	0	DF (+)	10	10	9
				E (-)	10	10	10	PF (-)	0	0	1

Note: H = Hip velocity during initial swing
K1 = Knee velocity during initial swing
K2 = Knee velocity during terminal swing
A1 = Ankle velocity during initial swing
A2 = Ankle velocity during midswing
F (+) = Flexion
E (-) = Extension
DF (+) = Dorsiflexion
PF (-) = Plantarflexion

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Table K.15 Comparisons of peak angular velocity (degrees/sec) of hip, knee, and ankle between groups (the healthy and the stroke) (n=10) and within group (affected and un-affected sides) in the sagittal plane (n=10)

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
H	COM	225.07±21.85	259.98±26.60	176.40±33.68	0.005*	0.001*	0.001*
	FAST	230.89±23.77	254.97±26.58	183.15±37.51	0.047*	0.003*	0.001*
K1	COM	349.83±35.94	351.28±66.69	296.74±70.67	0.952	0.048*	0.060
	FAST	353.93±37.78	356.02±28.60	330.75±64.87	0.890	0.342	0.332
K2	COM	391.38±30.11	408.50±73.20	196.36±63.96	0.503	0.001*	0.001*
	FAST	393.89±31.52	388.50±70.38	197.37±58.39	0.828	0.001*	0.001*
A1	COM	357.27±63.90	287.95±66.18	168.16±71.29	0.028*	0.001*	0.002*
	FAST	349.37±64.73	282.42±54.16	203.26±77.04	0.022*	0.001*	0.018*
A2	COM	170.65±34.70	177.33±49.10	77.64±49.13	0.729	0.001*	0.002*
	FAST	182.65±36.13	160.71±66.75	96.11±47.83	0.373	0.001*	0.080

Note: a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides
* = Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed
H = Hip flexor velocity during initial swing
K1= Knee flexor velocity during initial swing
K2 = Knee extensor velocity during terminal swing
A1 = Ankle plantarflexor velocity during initial swing
A2 = Ankle dorsiflexor velocity during mid swing

K 3.3 Ground reaction forces (%BW)

Ground reaction forces (GRFs) of the medio-lateral (X), antero-posterior (Y), and vertical (Z) directions were determined in this study. Seven GRFs comprised of X1, X2, X3, Y1, Y2, Z1, and Z2 were investigated (Figure K.9). Individual body weight was normalized to GRFs data before comparison.

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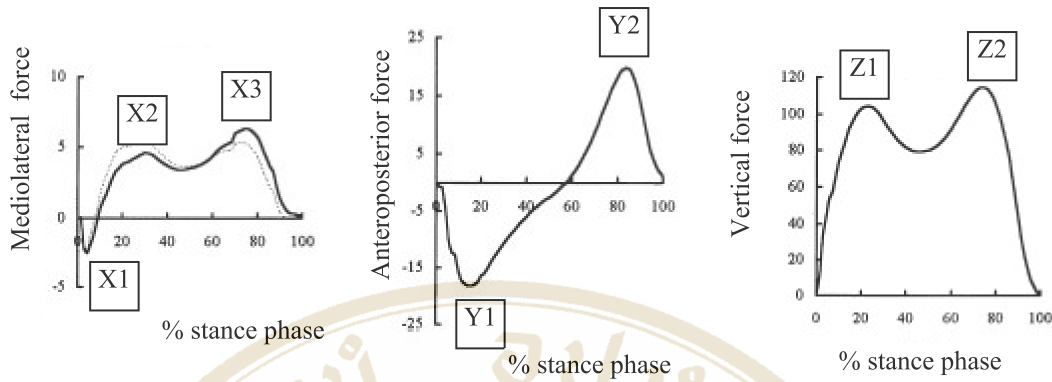

Figure K.9 Ground reaction forces in three axes.

Ground reaction forces in three axes of ten normal healthy and ten individuals with stroke in the comfortable and fast gait speeds were showed in Figures K.10 and K.11. In the GRFs graphs, the X-axis presents the frames and the Y-axis presents the force (%BW).

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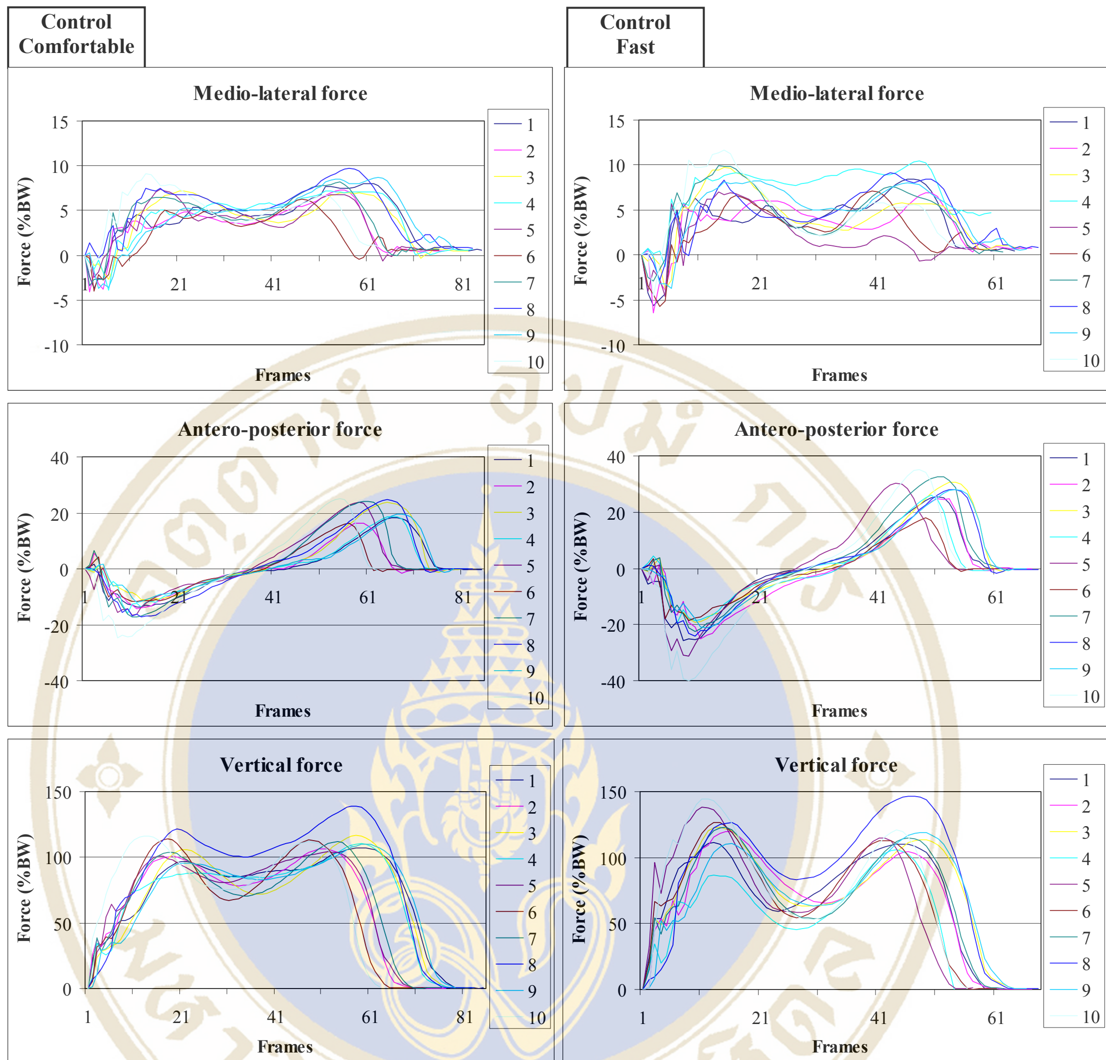

Figure K.10 Ground reaction forces in the medio-lateral (X), antero-posterior (Y), and vertical (Z) axes of normal healthy at comfortable and fast gait speeds.

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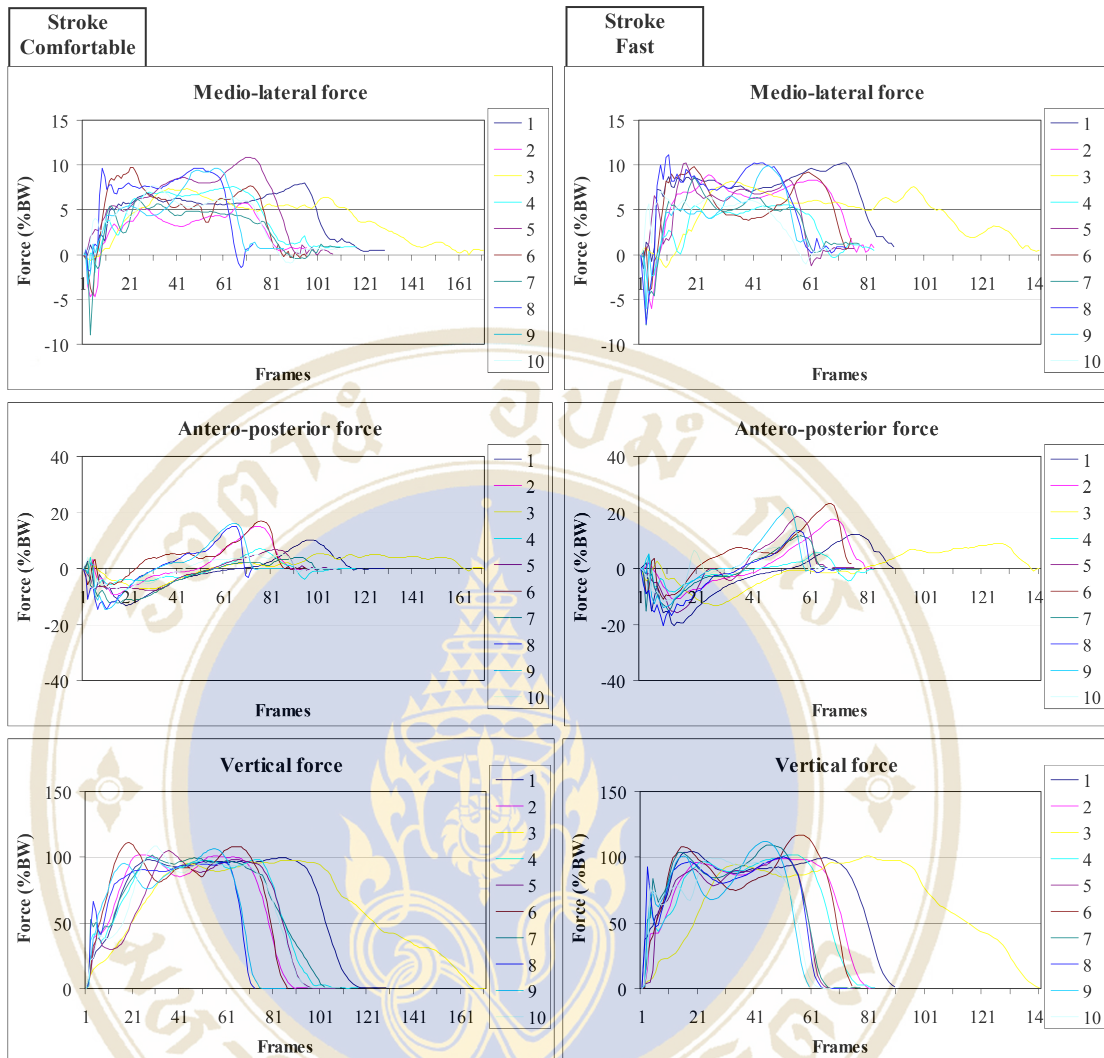

Figure K.11 Ground reaction forces in the medio-lateral (X), antero-posterior (Y), and vertical (Z) axes of normal healthy at comfortable and fast gait speeds.

Healthy and stroke subjects showed consistency GRFs in three axes at the comfortable and fast gait speeds. Only two individuals with stroke showed deviated force of the first peak medio-lateral force (X1) both in comfortable and fast gait speeds as shown in Table K.16. Positive and negative signs represent the direction of GRFs in each axis. In the X-axis, positive and negative signs represent the medial and lateral forces. In the Y-axis, positive and negative signs represent the propulsive and braking forces. In the Z-axis, positive sign represents the vertical force. The absolute scores of GRFs data were used to compare between the stroke and the healthy groups and also within stroke group (affected and un-affected sides) (Table K.17). There were significant differences in GRFs between the healthy and the un-affected of the stroke in Y1, Y2, and Z2 both in comfortable and fast speeds and in Z1 at the fast

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speed. Comparisons between the healthy and the affected of the stroke found significant differences in all GRFs data except the X1 and X2 at fast speed and Z1 at the comfortable speed. Significant differences were found in X2 and X3 at the comfortable speed between the un-affected and the affected of the stroke.

Table K.16 Number of subjects showing GRFs in three axes at comfortable and fast gait speeds

Comfortable gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
X1	**C**	**A**	**U**	**Y1**	**C**	**A**	**U**	**Z1**	**C**	**A**	**U**
Med (+)	0	2	0	Pro (+)	0	0	0	Vert (+)	10	10	10
Lat (-)	10	8	10	Bra (-)	10	10	10	(-)	0	0	0
X2	**C**	**A**	**U**	**Y2**	**C**	**A**	**U**	**Z2**	**C**	**A**	**U**
Med (+)	10	10	10	Pro (+)	10	10	10	Vert (+)	10	10	10
Lat (-)	0	0	0	Bra (-)	0	0	0	(-)	0	0	0
X3	**C**	**A**	**U**								
Med (+)	10	10	10								
Lat (-)	0	0	0								
Fast gait speed											
Variables	**Number of subject**			**Variables**	**Number of subject**			**Variables**	**Number of subject**		
X1	**C**	**A**	**U**	**Y1**	**C**	**A**	**U**	**Z1**	**C**	**A**	**U**
Med (+)	0	2	0	Pro (+)	0	0	0	Vert (+)	10	10	10
Lat (-)	10	8	10	Bra (-)	10	10	10	(-)	0	0	0
X2	**C**	**A**	**U**	**Y2**	**C**	**A**	**U**	**Z2**	**C**	**A**	**U**
Med (+)	10	10	10	Pro (+)	10	10	10	Vert (+)	10	10	10
Lat (-)	0	0	0	Bra (-)	0	0	0	(-)	0	0	0
X3	**C**	**A**	**U**								
Med (+)	10	10	10								
Lat (-)	0	0	0								

Note: X = Medial/Lateral GRF (+/-)
Med = Medial, Lat = Lateral forces
Y = Anterior/Posterior GRF (+/-)
Pro = Propulsive, Bra = Braking forces
Z = Vertical GRF (+)
Vert = Vertical force
A = Number of subject of affected side
U = Number of subject of un-affected side
C = Number of subject of control

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Table K.17 Comparisons of GRFs (%BW) between groups (the healthy and the stroke) (n=10) and within group (affected and un-affected sides) (n=10)

Variables	Speeds	Control (Mean±SD)	Un-affected (Mean±SD)	Affected (Mean±SD)	*p*-values[a]	*p*-values[b]	*p*-values[c]
X1	COM	3.70±1.18	2.60±2.13	2.15±1.67	0.168	0.028*	0.517
	FAST	5.37±1.73	4.31±2.52	3.54±2.84	0.287	0.098	0.340
X2	COM	5.46±1.07	5.61±2.04	7.97±3.10	0.834	0.026*	0.018*
	FAST	7.09±1.77	7.32±2.57	8.98±2.81	0.819	0.088	0.072
X3	COM	6.44±1.12	6.57±2.22	8.07±2.05	0.874	0.044*	0.039*
	FAST	6.77±1.05	6.87±2.42	8.46±1.79	0.905	0.020*	0.063
Y1	COM	15.53±3.94	9.88±4.03	10.27±3.15	0.005*	0.004*	0.759
	FAST	24.67±6.96	14.32±5.27	15.20±5.08	0.001*	0.003*	0.636
Y2	COM	20.81±2.62	13.41±4.09	9.38±4.05	0.001*	0.001*	0.062
	FAST	27.86±4.16	16.65±5.22	12.93±5.90	0.001*	0.001*	0.104
Z1	COM	101.32±13.58	98.01±3.40	100.44±6.32	0.464	0.855	0.216
	FAST	123.70±14.78	102.82±10.12	101.54±7.47	0.002*	0.001*	0.534
Z2	COM	111.13±9.78	102.22±4.52	100.14±3.38	0.017*	0.003*	0.194
	FAST	116.60±11.09	103.49±5.21	101.38±5.89	0.003*	0.001*	0.422

Note: a = *p*-value from Unpaired-t test between control and un-affected side
b = *p*-value from Unpaired-t test between control and affected side
c = *p*-value from Paired-t test between un-affected and affected sides
* = Significant difference at *p*-value<0.05
COM = Comfortable gait speed
FAST = Fast gait speed
X1 = 1st peak lateral force
X2 = 1st peak medial force
X3 = 2nd peak medial force
Y1 = Braking peak force
Y2 = Propulsion peak force
Z1 = 1st peak vertical force
Z2 = 2nd peak vertical force

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APPENDIX L
SAMPLE SIZE CALCULATION

This part was investigated for calculating number of subjects in each group. The objective of this study is, firstly, to determine the extent of relationships between clinical and biomechanic data in individuals with stroke and second, to compare the differences of gait biomechanic data between individuals with stroke and healthy Therefore, sample size calculation was based on comparative and correlation statistic methods.

L.1 Correlation statistic

- Correlation of clinical measures and gait speeds

From pilot study which done in 10 individuals with stroke, the relationships of clinical measures and gait velocities showed moderate relationships of Fugl-Meyer (r_p=0.551, p=0.099), BBS of affected side (r_p=0.568, p=0.087), whereas there was no relationship of the remain clinical variables and gait speeds, both comfortable and fast speeds.

- Correlation of clinical measures and gait symmetries

For this correlation section, number of subject is varied according to the pattern in gait symmetry index. There were clinical measures showing significant relationships with gait symmetries which are presented in Table L.1. Without the directional consideration, ranges of correlation coefficient of these relationships are 0.661-0.943 for Spearman rank correlation method and 0.674-0.909 for Pearson correlation method.

From the above correlation, it showed moderate to high relationship of clinical measures and gait performances (gait speed and symmetry). This study set the coefficient of correlation at 0.5 and power at 80 for relationship exist, estimating

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sample size for the correlation part was 30 subjects per group (Portney and Watkins 2000).

Table L.1 Correlations between clinical measures and gait symmetries

Symmetrical variable		Clinical measures	Correlation coefficient	Number of subj
Z1	COM	MAS of ankle invertors	r_s = 0.820*	6
	COM	MAS of knee extensors	r_s = 0.833*	6
	COM	Fugl-Meyer	r_s = -0.943**	6
	FAST	Fugl-Meyer	r_s = 0.943**	6
SST	COM	Fugl-Meyer	r_p = -0.836**	10
	FAST	Fugl-Meyer	r_p = -0.769*	9
Step time	COM	BBS_un-affected	r_p =-0.675*	9
	FAST	MAS of knee extensors	r_s = 0.765*	9
	FAST	Fugl-Meyer	r_p = -0.742*	9
	FAST	BBS_affected	r_p = -0.674*	9
	FAST	BBS_un-affected	r_p = -0.694	9
Stance time	COM	MAS of knee extensors	r_s = 0.798**	10
	COM	Fugl-Meyer	r_p = -0.831**	10
	FAST	Fugl-Meyer	r_p = -0.844**	10
Swing time	COM	MAS of knee extensors	r_s = 0.661*	10
	COM	Fugl-Meyer	r_p = -0.909**	10
	FAST	Fugl-Meyer	r_p = -0.855**	10

Note: Z1 = Vertical ground reaction force
SST = Single support time
r_p = Correlation coefficient from Pearson correlation statistic
r_s = Correlation coefficient from Spearman rank correlation statistic
*= Significant difference level set at p-value<0.05
** = Significant difference level set at p-value<0.01
COM = Comfortable gait speed
FAST = Fast gait speed

L.2 Comparative statistic

In the pilot study, comparisons of biomechanic data between the healthy subjetcs and individuals with stroke were detected by unpaired t-test. In addition, comparisons of affected and un-affected sides in individuals with stroke were detected

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by paired t-test. The comparisons were done in 10 individuals with stroke and 10 healthy subjects.

For unpaired t-test with equal variance results, sample size calculation was based on;

$$d = t\frac{\sqrt{n_1+n_2}}{n_1 n_2},$$

n_1, n_2 = number of subject in group one and group two

t = t-statistic value

For unpaired t-test with un-equal variance results, sample size calculation was based on;

$$s' = \frac{\sqrt{s_1^2+s_2^2}}{2} \quad \text{and} \quad d = \frac{\bar{x}_1 - \bar{x}_2}{s'},$$

$\bar{x}_1, \bar{x}_2$ = mean score of group one and group two

s_1, s_2 = standard deviation of group one and group two

For paired t-test statistic, sample size calculation was based on;

$$d' = \frac{\bar{x}_1 - \bar{x}_2}{s} \quad \text{and} \quad d = \frac{d'}{\sqrt{1-r}},$$

$\bar{x}_1, \bar{x}_2$ = mean score of group one and group two

s = standard deviation of both groups

r = correlation coefficient

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After calculation, number of subjects which based on comfortable speed are demonstrated in the Table L.2.

Table L.2 Number of subjects in each group

	Unpaired_equal Variance	d	n	Unpaired_un-equal Variance	d	n	Paired	d	n
TD	Cadence	1.94	<8	SST_U	1.93	<8	SST_U	2.04	<8
	Double	1.39	<8	step_time_A	2.14	<8	step_length_U	0.35	~100
	Step_width	1.72	<8				step_time_U	1.59	<8
	Stride_length	4.02	<8						
	Stride_time	1.60	<8						
	Gait_velocity	3.39	<8						
	SST_Af	0.05	>200						
	step_length_Un	3.07	<8						
	step_length_Af	3.90	<8						
	step_time_Un	0.98	~13						
Angle	IC_S_a_A	0.24	>200	IC_S_k_A	0.78	~20	IC_S_a_A	0.28	>200
	IC_S_a_Un	0.01	>200	IC_S_k_U	0.84	~20	IC_S_k_A	0.02	>200
	IC_S_h_Af	0.88	~20	MS_S_k_A	0.47	~50	MS_S_a_A	0.24	>200
	IC_S_h_Un	0.05	>200	TO_S_k_A	1.07	<8	MS_S_h_A	0.19	>200
	MS_S_a_Af	0.38	~100				MS_S_k_A	0.80	~20
	MS_S_a_Un	0.26	>200				TO_S_a_A	0.67	~30
	MS_S_h_Af	0.29	>200				TO_S_h_A	0.14	>200
	MS_S_h_Un	0.20	>200				TO_S_k_A	2.78	<8
	MS_S_k_Un	0.02	>200						
	TO_S_a_Af	1.48	<8						
	TO_S_a_Un	1.14	~13						
	TO_S_h_Af	0.68	~20						
	TO_S_h_Un	0.36	~100						
	TO_S_k_Un	1.70	<8						
GRFs	X1_A	1.07	~13	X1_U	0.64	~30	V_X1_A_com	0.31	~100
	X2_A	1.08	~13	X3_A	0.99	~13	V_X2_A_com	1.38	<8
	X2_U	0.10	>200	Z1_U	0.33	~200	V_X3_A_com	1.08	~13
	X3_U	0.07	>200				V_Y1_A_com	0.14	>200
	Y1_A	1.48	<8				V_Y2_A_com	1.04	~13
	Y1_U	1.42	<8				V_Z1_A_com	0.66	~20
	Y2_A	3.35	<8				V_Z2_A_com	0.64	~30
	Y2_U	2.15	<8						
	Z1_A	0.08	>200						
	Z2_A	1.50	<8						
	Z2_U	1.17	~13						

Note: TD = Temporo-distance variables
GRFs = Ground reaction forces
SST = Single support time
IC = Initial contact event
MS = Midstance event
TO = Toe off event
S = Sagittal plane
F = Frontal plane
T = Transverse plane
a = Ankle joint
h = Hip joint
k = Knee joint

A = Affected side data
U = Un-affected side data
X1 = 1st peak lateral force
X2 = 1st peak medial force
X3 = 2nd peak medial force
Y1 = Braking peak force
Y2 = Propulsion peak force
Z1 = 1st peak vertical force
Z2 = 2nd peak vertical force

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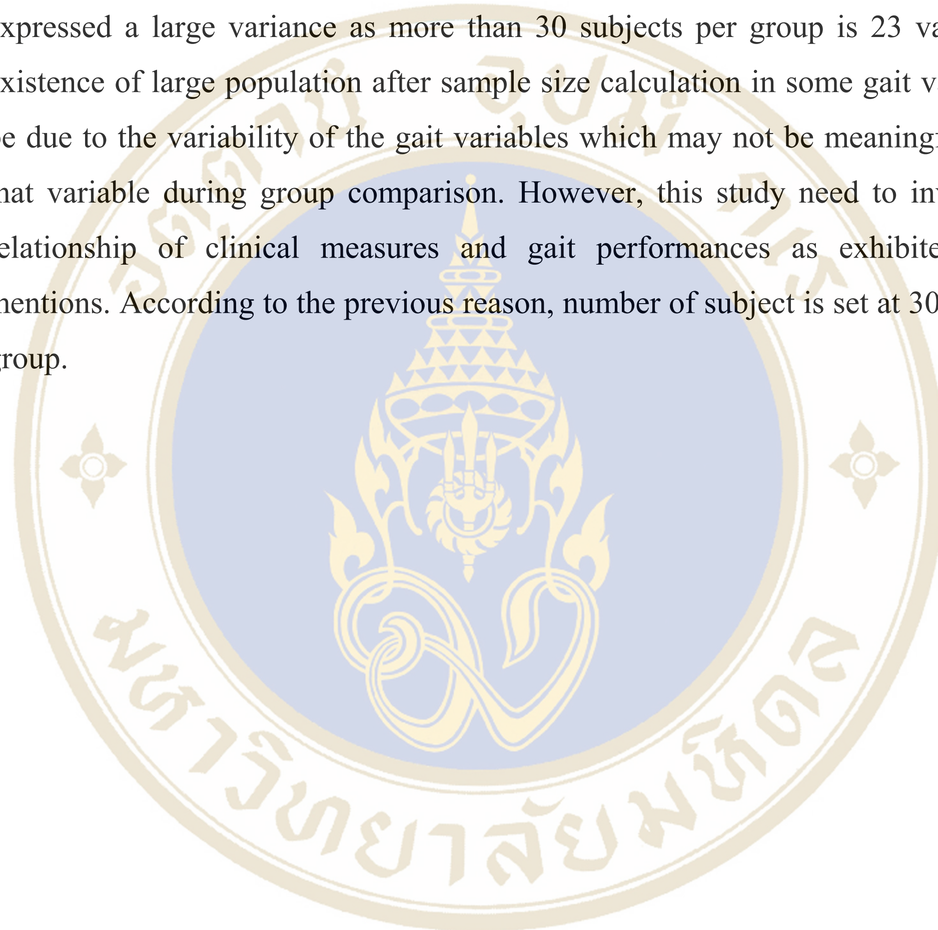
Conclusion

From the central limit theory, number of subject of 30 is appropriate for research analysis. After calculation, the estimated number of subject was shown in Table L.2. It was shown that number of subject in various biomechanical gait variables were vary from less than 8 to more than 200 subjects. Number of variables which expressed a large variance as more than 30 subjects per group is 23 variables. The existence of large population after sample size calculation in some gait variables may be due to the variability of the gait variables which may not be meaningful underline that variable during group comparison. However, this study need to investigate the relationship of clinical measures and gait performances as exhibited in above mentions. According to the previous reason, number of subject is set at 30 subjects per group.



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