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THE EFFECT OF ELECTROMECHANICAL GAIT TRAINER COMBINED WITH FUNCTIONAL ELECTRICAL STIMULATION FOR PERSONS IN THE SUBACUTE STAGE OF STROKE

BY

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CERTIFICATE OF ORIGINALITY

The idea of the present investigation and planning of the experiments resulted from discussions between me, Dr. Raymond Tong and Dr. Leonard Li.

All experiments in the present investigation were completed solely by me under the guidance of the supervisory committee.

I hereby declare that the work presented in this thesis is my own work, to best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

Ng Fung Wa

March, 2008

ABSTRACT

The purpose of this study was to investigate the effect of electromechanical gait trainer combined with functional electrical stimulation (FES) for persons in the subacute stage of recovery from stroke.

The study was a randomized controlled trial design with repeated measures. The dependent variables for this study were: motor strength, mobility, balance, functional ambulation, gait speed, activities of daily living and disability. Fifty-four participants suffered from stroke were recruited for this study. All participants were randomly assigned to the two treatment groups and one control group. Participants in the treatment groups (GT, GT-FES) experienced walking on an electromechanical gait trainer, with or without FES for 20 minutes for 20 sessions, totally 4 weeks. Three repeated measures on the motor and functional limitation were performed before, at the end of training period as well as 6 months follow-up.

Data was entered into version 14 of Statistical Package for Social Sciences (SPSS) for analysis. Repeated measure ANOVA showed that no difference was found between the demographic variables for the groups. Significant differences were found between the ‘gait trainer’ and ‘control’ groups at the end of the training period in terms of mobility identified on the Elderly Mobility Scale (EMS), functional walking ability identified on the Functional Ambulatory Category (FAC) and gait speed. Improvement in all variables was found across time with an interaction between time and the variables.

The FES with gait trainer group has showed better improvement than without FES, but no significant difference could be shown. The effects on both groups could be carried over to six weeks after interventions stopped.

This study is the first step in investigating interaction between two known-to-be effective therapeutic modalities for persons recovering from stroke, in a targeted intervention. Future study on large scale and blinded measurement was warranted to further understanding on the ambulatory recovery of stroke patients using an electromechanical gait trainer combined with FES.

PUBLICATIONS ARISING FROM THE THESIS

Ng MFW, Tong RK, Li LSW. A pilot study of randomized clinical controlled trial of gait training in subacute stroke patients with partial body weight support electromechanical gait trainer and functional electrical stimulation. Six-month follow-up. *Stroke.* 2008;39:154-160.

Tong RK**, Ng MFW,** Li LSW, and So EFM. Gait training of patients after stroke using an electromechanical gait trainer combined with simultaneous functional electrical stimulation. *Phys Ther* 2006, 86: 1282-1294.

Tong RK**, Ng MFW,** Li LSW**.** The effectiveness of gait training of body weight-supported cyclic walking exercise and functional electrical stimulation in patients with subacute stroke. *Arch Phys Med Rehabil* 2006;87:1298-1304.

Ng MFW, Tong KY, So EFM, Li LSW. The therapeutic effect of electromechanical gait trainer and functional electrical stimulation for patients with acute stroke. Abstract for the 4th World Congress for Neurorehabilitation 2006 Feb 12-16; China: Hong Kong. *Neurorehab and Neural Repair* 2006;20:97.

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LIST OF ABBREVIATIONS

ADL	activities of daily living
AFO	ankle foot orthosis
ANOVA	analysis of variance
BBS	Berg balance score
BWS	body-weight support
CT	computerized tomography
EMS	Elderly Mobility Scale
FAC	Functional Ambulation Category
FES	functional electrical stimulation
FIM	Functional Independence Measure
GS	gait speed
GT	walking exercise in the gait trainer
GT-FES	walking exercise in the gait trainer with functional electrical stimulation
HR	heart rate
ICC	intraclass correlation coefficient
KAFO	knee ankle foot orthosis
MFES	multichannel functional electrical stimulation
MI	Motricity Index
MRI	magnetic resonance imaging
NDT	neurodevelopmental technique
PNF	Proprioceptive Neuromuscular Facilitation
RCT	randomized controlled study
SCI	spinal cord injury
SSS	Scandinavian Stroke Scale

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Chapter 1

INTRODUCTION

Stroke is typically a disease of an aging adult and the risk of stroke doubles for each decade after the age of 55 (American Heart Association 2003) and becoming a growing financial burden, caused by the long-term disability and institutionalization after stroke and their impact on a variety of health care resources. Acute neurological impairments often resolve spontaneously, but persisting disabilities lead to partial or total dependence in activities of daily living in 25% to 50% of the survivors of the insult (American Heart Association 2003).

The consequences of stroke include impairments, functional limitations, and disability as classified by the Nagi model of disablement (Nagi 1965). Impairments are lost at an organ or body system level. Functional limitation, dependent on the number and magnitude of impairments, imply a restriction in an individual's ability to perform a task or physical action in a competent, expected manner, while disability infers an inability to engage in a prior role in the home or community (Ngi 1965). Numerous functional limitations may be present following stroke including, the inability to transfer, dress or walking fast. The slow speed of ambulation for individual's following stroke is reported in multiple studies (Brandstater et al. 1983, Friedman et al.1988, Finch and Barbeau 1986, Dettmann et al.1987). Individuals, following stroke, walked slower than their normal age. More than a half of people with stroke at the acute phase are not able to walk, and gait impairments are still present 3 months after stroke (Friedman et al. 1988, Finch and Barbeau 1986).

Effectiveness of gait training has become one of the goals in stroke rehabilitation.

Physical therapists working with individuals post stroke assume to the extent that improvements in impairments and functional limitations reduce disability (Nagi 1965). However, it has not been reported in the neurological literature that this theoretical is relevant to clinical practice or patient outcomes. Physical therapy interventions for persons recovering from stroke are based on a theory of motor control. The present day theory is based on the interaction of various subsystems as well as the motivation of the individual in the specific environment (Bernstein 1967). The classical theory of motor control is hierarchical in format and guided the practice of physical therapy through the middle of the twentieth century (Newton et al. 2001). Under this theory the central nervous system was solely responsible for motor control in individuals both before and after neurological injury. Bobath (1970) and Brunnstrum (1970) designed treatment paradigms based on this theory of motor control and its principles.

Task specific treatment paradigms fall under the current multi-system, interactive model of motor control (Carr et al. 1987). In several studies, early, intensive and gait-focused training on ambulatory ability in people at the early stage after stroke has been shown to be more effective than those attributable to spontaneous recovery and usual care (Richards et al. 1993, Visintin et al. 1998, Cunha IT et al. 2002, Duncan et al. 2003). These studies indicate that repetitive task-oriented exercise programs improve functional capabilities in individuals with neurological deficits. Task-specific machines, such as body weight-supported (BWS) treadmills and other robotic devices, have been developed for enhancing early post-stroke locomotor training. The treadmill appears to be an effective modality for early task specific gait training when the patients were still unable to carry full weight on their paretic limb during walking. Literature supports using a treadmill to improve gait speed for an individual recovering from stroke (Cunha IT et al. 2002, Hesse et al. 1995, Moseley et al. 2006, Visintin and Barbeau 1994). Significant changes in gait speed have been found in as few as 12 treatment sessions (Ada et al. 2003). Studies by Cunha IT et a (2001) and Visintin et al (1994) showed that BWS treadmill ambulation training was a feasible and safe technique and had a promising role in gait training for people with acute stroke. However, the Cochrane systematic reviews surveyed all 15 trials (622 participants) and found there were no statistically significant differences between treadmill training with or without body weight support and other types of interventions for walking speed or dependence (Moseley et al. 2006).

A new gait-training machine, an electromechanical gait trainer (GT II)* with BWS, was developed by Hesse et al. (2000) was shown to be an effective alternative to treadmill therapy with partial body weight support in intense gait rehabilitation for wheelchair-bound stroke survivors to practice a gait-like movement with minimal therapist assistance Hesse and Uhlenbrock (2000). Another approach that combines Functional electrical stimulation (FES) with the electromechanical gait trainer simultaneously is now getting more concerns. FES has major therapeutic benefits in the early phase of gait rehabilitation, facilitating people with brain injury to achieve a better functional result in terms of strength and motor recovery in a shorter period of time (Malezic et al. 1987, Kralj et al. 1993). Graded sensory stimuli with meaningful muscle active participation (i.e., sensorimotor coupling) may cause plasticity in cortical sensorimotor representation areas (Gibson 1969, Schmidt 1988).

The purposes of this study were to compare the effectiveness of 3 gait training interventions in the subacute stroke stage to determine the extent of mobility or muscle strength recovery and the carryover from machine training to over-ground locomotion and, perhaps to suggest the extent of the recovery process after stroke in the long term. Our hypothesis was that early intensive gait-oriented training by gait trainer combined with FES could be an effective intervention for stroke survivors.

Chapter 2

LITERATURE REVIEW

2.1 Stroke

Stroke or cerebrovascular accident (CVA) is the clinical designation for a rapidly developing loss of brain function due to a disturbance in the blood vessels supplying blood to the brain (Cotran et al 2005). This phenomenon can be due to ischemia caused by thrombosis or embolism, or due to a hemorrhage.

2.1.1 Demographics and Pathophysiology

Stroke is typically a disease of the aging adult. The consequences of stroke include physical, emotional, and financial. The physical and emotional consequences of stroke, as related to this study, are addressed in this review of relevant literatures.

According to Tengs et al. (2001), 4 million people in the United States who have survived a stroke and are living with the consequences of this disease. The risk of stroke doubles for each decade after the age of 55 (American Heart Association 2003). Other risk factors associated with stroke are smoking, obesity, physical inactivity, high cholesterol, and hypertension. Additional risk factors include gender, race, family medical history, and history of prior stroke. The American Heart Association (2003) refers to stroke as a “brain attack” that can be ischemic or hemorrhagic in origin. Stroke is either ischemia or hemorrhagic. Insufficiency of blood supply is termed ischemia; if it is temporary, symptoms and signs may be found with little or no pathological evidence of tissue damage (Bryan et al. 1991).

Ischemic stroke accounts for about 83% of all cases. Types of ischemic stroke are thrombus and embolus. A thrombus is a clot that develops in an atherosclerotic vessel. Since thrombotic strokes are slow to develop, the brain often develops collateral circulation in the area, which may account for less devastating motor loss of the individual with this etiology of stroke (Barnett et al. 1992).

Impairments from ischemic stroke are directly correlated to site of infarct (Ryerson 2001). With occlusion of the middle cerebral artery, for example, the paresis with an infarct in the middle cerebral artery is greater in the arm than the leg. Anterior artery occlusions spare the centers for speech and language but may result in paresis of the opposite foot and leg and to a lesser extent the arm, sensory impairments, mental impairments, motor apraxia and urinary incontinence (Ryerson 2001).

2.1.2 Epidemiology and risk factors

Stroke is now the third leading cause of death in the Western world, after the first and second leading cause: heart disease and cancer respectively (Feigin 2005). It causes 10% of worldwide deaths (World Health Organization 2004). The incidence of stroke increases exponentially from 30 years of age, and etiology varies by age (Ellekjær 1994). About twelve thousands registered stroke patients in eleven countries were included in the WHO MONICA project (Stegmayr et al. 1997) identified the highest attack rates with first and recurrent stroke in men in Finland and Russia (350/100 000 per year). Their attack rates were three times higher than the lowest rates found in Italy and Germany. In women, the highest attack and incidence rates were seen in Russia, where stroke events were more than three times higher than in Italy. In half of the eleven national populations of the WHO MONICA study, the stroke incidence was twice as high in men compared to women (Stegmayr et al. 1997). In this population survey of eleven countries, the presence of smoking and elevated blood pressure explained 21% of the variation in stroke incidence in men and 42 % in women (Stegmayr et al. 1997).

Stroke is a major cause of long-term disability (Foulkes et al.1988) and has potentially enormous emotional and socioeconomic results for patients, their families, and health services. Lifetime costs per patient are estimated at between US$59 800 and US$230 000 (Caro et al. 2000). Patients after stroke were associated with an almost 5-fold increase in risk for death between 4 weeks and 1 year after a first stroke and 2-fold increase in the risk for death subsequent to 1 year (Bronnum-Hansen et al. 2001). Stroke-related disability may explain this excess mortality from cardiovascular diseases, cancer, suicide, accidents and other diseases after nonfatal strokes. A degree of disability after a stroke could make the patient ineligible for cancer therapy or other diseases and post-stroke fall accident and depression might lead to increase death rate (Bronnum-Hansen et al. 2001).

2.2 Stroke and Motor Control

2.2.1 Hierarchial theory

The central motor system can be subdivided into three levels (Bear et al. 2001). The highest level, represented by the association areas of cortex and basal ganglia of the forebrain, is responsible with motor strategy. The middle level, represented by the motor cortex and cerebellum, is responsible the sequences of muscle contractions, arranged in space and time, resulted in smooth motor performance. The lowest level, represented by the brain stem and spinal cord, is concerned with motor execution including activation of the motor neuron and interneuron pools that generate the goal-directed movement and make any necessary adjustments of posture. The correct function of each level of the motor control hierarchy relies on sensory information feedback. At the highest level, sensory information generates a mental image of the body and its relationship to the environment. At the middle level, tactical decisions are based on the memory of sensory information from past movements. At the lowest level, sensory feedback is used to maintain posture, muscle length, and tension before, during and after each voluntary movement (Bear et al. 2001).

2.2.2 Current Theory of Motor Control and Walking

It is common in stroke that infarction or hemorrhage involves the sensory-motor system. Shepherd has described impairments in muscle activation and motor control (Shepherd 2001). Muscle weakness, one of the major motor deficits, is due to loss of motor unit activation, changes in firing rates, and changes in recruitment order. Weakness from these sources is confounded by changes in the properties of motor units and in morphological and mechanical changes in the muscles, which occur adaptively as a consequence of denervation, but also of decreased physical activity and disuse. Muscle weakness and disordered motor control combine to evoke the functional movement disability.

Postural stability consists of the static balance, with minimal postural sway and the dynamic balance in a controlled manner (Nichols 1997). Postural control includes both inborn reactions and those built up by learning. The sensory-motor organization for postural orientation includes neural mechanisms for active control of joint stiffness and variables such as trunk and head alignment (Kandel et al. 2000).

Walking is cycling repetition of stepping on the hind legs that could be induced in cats and dogs after complete transaction of the spinal cord. There are different kinds of preparations used in studies of the neural control of stepping (Kandel et al. 2000). When supported on a motorized treadmill both decerebrate cat preparations walk with a coordinated stepping pattern in all four limbs, and the rate of stepping is matched to the treadmill speed. These decerebrate preparations demonstrate that the basic rhythmicity of stepping is produced by neuronal circuits contained entirely within the spinal cord. The stepping movements in these spinal preparations were similar to normal stepping. This means, that supraspinal structures are not necessary for producing the basic motor pattern for stepping. The locomotor rhythm is generated spontaneously, while in the other it is evoked by electrical stimulation to the mesencephalic locomotor region (Shik et al. 1969). Already in 1911 Brown showed, that rhythmic locomotor patterns were generated even after complete removal of all sensory input from the moving limbs (Brown

1911). The spinal circuits can be activated by tonic descending signals from the brain. The neuronal networks capable of generating rhythmic motor activity in the absence of sensory feedback are termed central pattern generators (CPG) (Richards et al. 1999). Descending signals, drugs, or afferent signals could modify the temporal motor activity pattern by altering the functioning of interneurons in the patterning network. Three important types of sensory information are used to regulate stepping: somatosensory input from the receptors of muscle and skin, input from the vestibular apparatus, and visual input. Input from proprioceptors in muscles and joints are involved in automatic regulation of stepping. Exteroceptors are located in the skin and adjust stepping to external stimuli. Exteroceptors have a powerful influence on the CPG for walking.

Although the basic motor pattern for stepping is generated in the spinal cord, fine control of walking involves numerous regions of the brain, including the motor cortex, cerebellum, and various sites within the brain stem (Kandel et al. 2000). Supraspinal regulation of stepping includes activations of the spinal locomotor system, controlling the overall speed of locomotion, refining the motor pattern in response to feedback from the limbs and guiding limb movement in response to visual input. Human locomotion differs from four-legged animal locomotion in that it is bipedal, placing significantly greater demands on the descending systems that control balance during walking. The spinal networks that contribute to human locomotion are more dependent on supraspinal centers than those in quadrupedal animals.

Walking occurs once the equilibrium ceases to exist because of the change of internal forces caused by muscle activity (Popovic and Sinkjaer 2003).

Human walking starts after the redistribution of internal forces allowing the center of gravity to take over the stability zone. Once the first leg supports the body weight and then the other leg pushes the body up and forward due to the momentum, and thus the body will move in the direction of progression, and ultimately come directly above the supporting leg. Falling is prevented by bringing one leg in a new support position in front of the body. This inverted pendulum position is transitional; momentum and gravity will again bring the body into the falling pattern.

Two types of impaired motor control, which appear immediately after stroke, particularly affect gait performance. These are weakness or loss of volitional movement of the arm and leg on the side opposite to the brain lesion, known as paresis and inappropriately timed or graded muscle activations (decreased descending inputs, reduced motor unit synchronization as reviewed by (Shepherd 2001). Other types of disruptions that appear later include hyperactive stretch reflexes and hypoextensibility of the muscle-tendon complex (Richards et al. 1999).

2.2.3 Characteristics of hemiplegic gait

An estimated 70% of the patients who survive a stroke are unable to walk independently during the first three to four weeks post-stroke (Friedman 1990). Indeed, regaining independent walking ability forms a major goal of all rehabilitation programs and is of great significance to patients who have suffered a stroke. Although the reported figures vary, approximately 50-85% of the patients who survived a stroke will eventually regain some degree of walking ability (Friedman 1990). Several studies show that most of the motor recovery following stroke occurs within the first 3 months post-stroke and that the initially steep recovery curve levels at about 6 months to a year post-stroke (Friedman 1990).

The population of stroke patients is a heterogeneous group. Severity but also location and type of stroke determine to a large extent the symptoms and outcome. Hence, patients who eventually regain some form of walking ability may vary greatly in walking speed, spatio-temporal characteristics and kinematic gait patterns. Nevertheless, in a number of studies it was attempted to classify hemiplegic gait patterns (Knutsson and Richards 1979, Griffin et al 1995, De Quervain et al. 1996, Olney et al. 1998) and it appears that some specific movement patterns can be observed in sub-groups of patients. The average walking speed of stroke patients is lower than that of healthy controls but the reported values vary depending on the severity of the stroke, the time post-stroke and the age of the subjects (Mulroy et al. 2003). Compared to healthy controls, patient's stride lengths are smaller and the duration of gait cycles is longer (Olney and Richards 1996).

Hemiplegic stroke patients also show prolonged double support phases in their gait cycle, especially the double support phase that precedes the swing phase of the hemiplegic side. It is assumed that this is caused by a prolonged duration of the pre-swing phase on the hemiplegic side, as a result of insufficient power and inappropriate initiation of hip flexor muscles (Griffin et al. 1995). Furthermore, the single support phase on the hemiplegic side is relatively short in relation to the duration of a complete cycle (Griffin et al. 1995, Mulroy et al. 2003).

General gait patterns in patients with stroke include with a toe-first or entire sole down during stance and toe drag or inversion of the foot during swing have been observed (Wall and Ashburn 1979, Colaso and Joshi 1971). Compared to non-disabled subjects, findings showed that patients with stroke have decreased walking velocity, cadence, and stride length, and an increased gait cycle. These results also showed a decreased ability to bear weight on the hemiplegic side (von-Schroeder et al.1995, Brandstater et al. 1983).

Concerning patterns in joint kinematics, Olney (1998) and Richards (1999) concluded in their studies that hemiplegic gait can be classified by a combination of (1) a reduced hip joint angle amplitude in the sagittal plane, caused by a decreased hip flexion at heel-strike and a decreased hip extension at toe-off, (2) a reduced knee joint angle amplitude caused by increased knee flexion at heel-strike and decreased knee flexion at toe-off and during swing and (3) increased plantar-flexion of the ankle at heel-strike and during swing and decreased plantar-flexion at toe-off. Abnormalities in these joint kinematics often lead to secondary compensations in other body segments. For example, a reduced knee flexion during swing can be accompanied by circumduction or upward pelvic tilt (Wall and Turnbull 1986, Kerrigan et al. 1999).

2.2.4 The relation between gait characteristics and functional recovery

Functional recovery of walking ability is often quantified by employing clinical measures, such as the Bartel Index (Kerrigan et al. 2000, Mahoney and Barthel 1965), the Rivermead Mobility Index (Collen et al. 1991) or the Functional Ambulation Categories (Holden et al. 1984) but also gait velocity (Collen et al. 1990) or walking distance (Cunha et al. 2002) are frequently used as measures for recovery. Recovery of body functions, such as muscle strength, can be assessed by measures such as the Fugl Meyer (Fugl-Meyer 1980) or the Motricity Index (Demeurisse et al. 1980). It is clear that these measures correlate highly: when body functions such as muscle strength recover to normal, chances are high that functional recovery of walking ability will be present as well. Another means of recording recovery of gait after stroke is gait analysis in which the specific characteristics of hemiplegic gait patterns can be analysed. Again, patients whose gait patterns recover towards a normal gait pattern will most likely show functional recovery (Roth et al. 1997, Schauer and Mauritz 2003).

2.3 Gait Rehabilitation of Stroke Patients

Neurorehabilitation is increasingly taking into account in scientific findings. Recent changes in intervention strategies include placing more emphasis on active exercise and task specific training as well as active and passive methods of preserving muscle extensibility (Shepherd 2001). Walking training should, therefore, include exercises to strengthen weak muscles, to preserve muscle extensibility, plus the practice of walking. Training has the potential to promote brain reorganization and to optimize functional performance. Rosebaum (1991) has pointed out that movement becomes more skilled with learning, and this is probably due to improvement in timing, tuning, and coordinating muscle activation. Motor learning and developing the walking skill require practice with concrete goals and objective feedback about its effectiveness. The learner must have the opportunity to practice actively and to understand the importance of frequent repetitions.

2.3.1 Bobath and Proprioceptive Neuromuscular Facilitation (PNF) Theories

Traditional physiotherapeutic approaches to gait re-education have focused primarily on spasticity and abnormal reflexes. Neurodevelopmental Technique (NDT) established by Bobath (Bobath 1978, Davies 1990) assumes that an abnormal postural reflex activity is the major cause of dysfunction, and as such a significant proportion of therapy time involves inhibiting spasticity and other abnormal responses. In the Brunnstrom technique, synergistic movements are used to strengthen and practice single movements (Brunnstrum 1970).

Proprioceptive Neuromuscular Facilitation (PNF) (Voss et al. 1985) techniques consist of assisted isometric and isotonic leg flexion-extension exercises, which are thought to improve strength and control of leg musculature in preparation for walking. Hesse et al. (1994) studied the influence of NDT technique on gait. 148 patients (mean 130.5 days post-stroke) received 45 min of physiotherapy based on Bobath concept, five times per week during four weeks of rehabilitation. Additionally, patients were instructed in a self-administered training program for at least 30 min daily. They assessed gait symmetry and absolute changes of vertical ground reaction forces. Both parameters are process-oriented variables of the Bobath technique in which physiotherapists who are trained in NDT strictly control weight acceptance and push-off of both lower limbs. Stance duration, weight acceptance, push-off of both legs, and the stance duration symmetry improved, independent of changes of gait velocity. The symmetry of the ground reaction forces did not improve. Heel strike and the loading rate worsened at the end of four weeks of treatment.

2.3.2 Active bracing assisted walking

Therapeutic methods to improve gait have traditionally included walking with essential walking aids and with verbal and manual guidance. Walking aids allows the therapist to begin to walk with patients who still require mild to moderate assistance. The therapist stands on the paretic side and prevents the patient's pelvis from shifting away, and advances the patients's paretic leg. Knee buckling due to knee extensor weakness during single stance phase on the paretic leg and toe-first and toe drag or inversion of the foot due to spasticity or synergic pattern during swing can be controlled passively with an ankle foot orthosis (AFO), an AFO and knee splint, or a knee ankle foot orthosis (KAFO) (Kosak and Reding 2000). Walking exercises are undertaken usually on the floor, but also in other circumstances such as on stairs or outdoor. Using a limb-load monitor feedback, resisted exercises in the upright position with an isokinetic device and walking on a treadmill can also be used in task-specific intensive walking training program (Richards et al. 1993).

2.3.3 Body Weight Supported Mechanical Gait Training

2.3.3.1 Treadmill training

There are a great number of people who have lost the ability to walk following stroke. In stroke rehabilitation the use of the treadmill is increasingly mentioned as an alternative method of gait training, although it has yet to be widely used in clinical settings (Richards et al. 1993, Visintin et al. 1998, Hesse et al 1995, Waagfjord et al. 1990). Body Weight Supported (BWS) gait training with manual assistance of the legs and pelvis is a promising new therapy method for patients following neurological injuries. The BWS system consists of a crane that can suspend the patient's body above the treadmill. The patient wears a harness so that the BWS device can be hooked on. More advanced BWS systems have a passive or active suspension mechanism to control the amount of support precisely. Usually the therapy starts with a higher percentage of body weight supported, the amount of support is then gradually reduced as the patient gets stronger and more stable during the training period (Hesse et al. 1995, Waagfjord et al.1990).

One of the major advantages of using BWS is that task-specific gait training can be started during the very early days of rehabilitation by providing patients as much weight support as needed to compensate for their inability to assume an upright position while stepping forward. This has major implications for those patients who are very impaired and thus difficult to gait train, sometimes requiring up to three therapists to walk a short distance over ground (Visintin et al. 1998). For these patients, BWS and treadmill can be used to provide early and intensive task-specific gait training that will potentiate their locomotor recovery (Richards et al. 1993). If chronic nonambulatory patients with neurological conditions can resume ambulation after training with BWS and treadmill, as reported by several authors (Hesse et al. 1994, Wernig and Muller 1992, Barbeau et al. 1993), this training strategy should have a substantial impact when implemented during the acute phase of rehabilitation when there is the most plasticity and potential for recovery.

It is currently hypothesized that the repetitive gait-like motion produces patterns of sensory inputs that can simulate the un-damaged parts of the nervous system, promoting reorganization of its functions (Shepherd 2001). It would be more desirable to practice walking in order to learn to walk than to practice standing only. The sensation of loading the unloading then stimulates the nervous system, encouraging its reorganization. However, it is generally impossible or difficult for patients to stand up and begin to walk by themselves. The idea of BWS is, then, to give the patients a safe environment in which they can practice walking to feel what it was like to walk. The over-head BWS system enables the patient to stand up steadily against gravity and the treadmill and manual assistance guide the patient to follow a gait-like motion. The overall physical fitness of the patient can also be improved gradually with this training (Visintin et al. 1998, Cunha TI et al. 2002, Hesse et al. 1994, Wernig and Muller 1992, Barbeau et al. 1993).

Ada et al. (2003) studied four weeks of gait training consisting of both treadmill and overground walking. Thirteen chronic stroke patients (7 – 60 months post-stroke) practiced three times per week for 45 min at a time for 4 weeks totally. The treadmill component was structured to increase step length, speed, balance, fitness, and automaticity. The overground walking component aimed to reinforce improvements in walking pattern and speed achieved on the treadmill. It was defined as whole-task practice involving propulsion forward, backward, or sideways, or stairs climbing. The study was carried out in an A-B-A single case study with seven patients. In nonambulatory hemiparetic patients trained with BWS treadmill training (A-phase) was shown to be more effective than physiotherapy based on the commonly used Bobath (B-phase) concept in improving gait. The first three-week phase (A-phase) consisted of 30 min treadmill training each workday. The subsequent three week (B-phase) consisted of 45 min physiotherapy sessions daily followed by another A-phase. The gait parameters improved only during the A-phases.

In another study of the 79 subacute hemiparetic patients (27 – 148 days post-stroke) with abnormal gait patterns, six weeks of training at a frequency of four times per week, 20 min at a time on a treadmill with BWS or without BWS was compared (Visintin et al. 1998). Patients in the BWS group were provided with up to 40 % BWS at the beginning of training, and the percentage of BWS was progressively decreased as the patient's gait pattern and ability to walk improved. Patients in both groups showed improvements in balance, motor recovery, walking speed, and endurance when scores at post-training and at three months follow-up were compared. However, the patients started with BWS, scored significantly higher for those variables and they continued to have higher scores for over ground walking speed and motor recovery at the three-month follow-up assessment.

In the study of Werner et al. (2002), 28 non-ambulatory stroke patients (2 – 8 months post-stroke) participated in a comprehensive 9-week rehabilitation program. The first 3-week period consisted of daily physiotherapy, occupational, speech and neuropsychological therapy according to individual need. During the subsequent 3 weeks of specific intervention, patients in group A received treadmill training with BWS for 30 min and other forms of physiotherapy for 40 min five times a week. Physiotherapy following the Bobath concept included gait preparatory maneuvers in sitting and standing and the practice of gait itself either on the floor or on the stairs. The patients in group B received only treadmill training with BWS for 30 min five times a week. Afterwards, patients in both groups participated in a comprehensive rehabilitation program for another 3 weeks. Patients regained better walking ability by treadmill training with BWS plus physiotherapy. However, it has to be noted that the group A received twice as much therapy as group B. The result may be influenced by the treatment intensity in additional to the type of the treatment itself.

2.3.3.2 Robotic-assisted devices

Gait training with BWS plus manual assistance of the legs and pelvis is a promising new therapy method. However, the current method of BWS gait training has limitations. First of all, it is difficult to quantify and control the training. The manual assistance provided can vary greatly between trainers and training sessions (Moseley et al. 2006). As a result, the pattern of sensory input to the nervous system can also vary greatly between trainers and sessions. Secondly, the therapy is highly labor intensive, requiring three professional trainers to assist the patient’s legs and torso and to operate the treadmill and BWS during each training session, and they can get fatigued quickly. As a result, BWS gait training is labor-intensive, costly and not readily available for the majority of patients. Use of robotic-assisted devices can potentially overcome those limitations.

If robotic-assisted devices could replace some of the workload on trainers, the benefit will be significant. Then, the cost can also be reduced, and the therapy would become more widely available. The duration and frequency of gait training would not be limited by the physical strength or endurance of the trainers. The therapy can then be optimized for cost-effectiveness regardless of the physical limitations of human trainers. Robotic-assisted devices can measure the patient's parameters during the gait training. The recorded data can then be systematically analyzed. With such measurements and analysis, it is possible to quantify and evaluate the quality and effectiveness of the therapy objectively. In addition, robotic-assisted devices allow researches to explicitly control the form and amount of assistance or load applied to the subject during training. Thus, different therapy methods can be designed, tested and compared.

2.3.3.2.1 Electromechanical gait trainer

Hesse and his coworkers designed and produced a mechanical gait trainer, enabling patients to perform repetitive practice of gait-like movement without overstraining the therapists (Hesse et al. 2000, Hesse and Uhlenbrock 2000). In the device, the patients are supported by a harness and stand with their feet on the motor-driven footplates. Patients can practice gait-like movements on the gait trainer, and this is intended to achieve better symmetry of posture, larger hip extension during stance, less knee flexion and less ankle plantar flexion during swing when compared with the treadmill walking (Hesse et al. 1999b). Only one therapist is necessary to assist the patient on the gait trainer. In a study of subacute, nonambulatory stroke survivors performing six weeks of walking exercises (Werner et al. 2002b), no differences were found between treadmill training with BWS and gait trainer exercises using such outcome measures as Functional Ambulation Category, gait velocity, Rivermead Motor Assessment or Modified Ashworth Score. The gait trainer was at least as effective as treadmill therapy with partial body weight support but required less input from the therapist.

2.3.3.2.2 Lokomat

The Lokomat consists of a robotic gait orthosis and a body weight support system. This system is generally called as robot drive walking exercise. The orthosis is position controlled. The patient's legs are guided according to a pre-programmed physiological gait pattern. The computer controlled guidance allows individual adjustments of different gait parameters (Krewer 2007).

The Lokomat System utilizes high quality computer controlled motors (drives) which are integrated in the gait orthosis at each hip and knee joint. Force transducers at the joints accurately measure the interaction between the patient and the Lokomat. The drives are precisely synchronized with the speed of the treadmill. The Lokomat Robotic Gait Orthosis is adjustable to the patient's anatomy. Hip and knee joint angles are controlled in real time by software to achieve a physiologically meaningful gait pattern. Each of the four joints is constantly monitored by computer software to ensure that they are precisely held to the predefined gait pattern (Krewer 2007). A user interface allows the therapist to easily operate the Lokomat and adjust training parameters to suit the individual patient's needs at any point during a training session. The Lokomat is designed to automate locomotion therapy on a treadmill and improves the efficiency of treadmill training. It showed innovative possibilities for gait training in stroke rehabilitation while eliminating prolonged repetitive movements in a non-ergonomic position during conventional physiotherapy training (Mayr 2007). This seems that machine based or computerized control device were not only have the advantage of reducing the labor loading but also showed promising role in stroke rehabilitation.

Husemann and co-workers conducted a randomized, controlled study of 30 acute stroke survivors (Husemann et al 2007). The treatment group received 30 minutes of daily robotic training using Lokomat and the control group 30 minutes of conventional physiotherapy daily in addition to 30 minutes of conventional physiotherapy for each group. Outcome measures were independence of gait, gait speed, gait parameters, and body tissue composition. After 4 weeks of therapy, the walking ability of the Lokomat group and the control group expressed as the functional ambulation classification was significantly improved. There was no significant difference in gain of these parameters between the groups. The Lokomat group had a significantly longer single stance phase (sec; mean+/-SEM) on the paretic leg when walking on the floor.

Another study included sixteen stroke patients, mostly within 3 months after onset, were randomized into 2 treatment groups, ABA or BAB (A = 3 weeks of Lokomat training, B = 3 weeks of conventional physical therapy) for 9 weeks of treatment (Mayr 2007). The result of this study suggested that the Lokomat robotic assistive device provided innovative possibilities for gait training in stroke rehabilitation while eliminating prolonged repetitive movements in a nonergonomic position during conventional physiotherapy training.

2.3.4 Functional Electrical Stimulation for Gait Training

In individuals with paralysis due to upper motor neuron dysfunction, functional electrical stimulation (FES) of peripheral nerves can be used to substitute for loss of voluntary motor control by the central nervous system (CNS) (Daly et al. 1996). FES can help manage of foot drop in individuals with hemiplegia following stroke (Bogataj et al. 1997, Daly and Ruff 2000). The single channel electrical stimulation to prevent foot drop in stroke patients was introduced already in 1961 (Liberson et al. 1961). Different peroneal stimulators in stroke patients have been studied in several studies (Taylor et al. 1999, Granat et al. 1996). The FES stimulation is a symmetrical biphasic output waveform. It is normally delivered with using 0.3 ms pulse duration, frequencies of 25 up to 50 Hz and amplitude of 20 mA up to 60 mA (Burridge et al 1998). Stimulated ankle dorsiflexion was produced by using surface electrodes, with the cathode on the skin close to the peroneal nerve as it passes around the head of the fibula and the anode on the motor point of the tibialis anterior or in the popliteal fossa.

Bogataj et al. (1995) compared multichannel-FES (MFES) to conventional therapy in 20 subacute stroke patients. During the MFES therapy period, the conventional gait therapy was replaced by MFES-assisted gait training. Each MFES therapy session lasted from 30 minutes to one hour with MFES being delivered with surface electrodes on the peroneal nerve for ankle dorsiflexion, the soleus muscle for ankle plantar flexion, the hamstring muscles for knee flexion, the quadriceps femoris musculature for knee extension, the gluteus maximus muscle for hip extension and stabilization of the pelvis during stance, and optionally the triceps brachii muscle for reciprocal arm swing during the swing phase of gait for the ipsilateral leg. The stimulation was electrically synchronized to the gait pattern. It was delivered, when the patients walked on a 100-m walkway. They found that progress during MFES combined with traditional therapy was better than could be achieved by conventional therapy alone. The improvement was assessed by gait speed, stride length, gait cadence.

The review by Daly et al. (1996), stated that the stimulation was useful, but the more muscles which were stimulated, the better improvements in gait to be expected. MFES has also been combined with BWS treadmill training resulting in an improvement in the walking ability of non-ambulatory chronic stroke patients (Hesse et al. 1995b). The study was carried out in an A-B-A single case study design with seven patients. The first three week phase (A-phase) consisted of 30 min BWS treadmill training with FES each workday. The subsequent three weeks (B-phase) consisted of 45 min comprehensive neurodevelopment physiotherapy sessions daily. The walking ability (FAC) and gait velocity improved only during the A-phases.

In 2006, a Cochrane review was conducted to determine if electrical stimulation improved functional motor ability and the ability to perform activities of daily living following stroke (Pomeroy et al 2006). Twenty-four randomized controlled trials that met inclusion criteria compared electrical stimulation to no treatment or to physical therapy alone. Results were combined and analyzed. The authors note limitations in the trials including variations between studies in time after stroke, functional levels and dose of electrical stimulation and the possibility of selection and detection bias in the majority of the trials reviewed. The authors concluded that data is insufficient and more research is needed to address question related to the type and dose of electrical stimulation and the time for treatment following stroke.

Chapter 3

METHODOLOGY

The objectives of this study were (1) to determine and compare the therapeutic effect of the electromechanical gait trainer alone or combined with FES for patients in the subacute stroke stage; and (2) to determine the extent of effectiveness of the training in improving mobility and locomotion ability of the recovery process after stroke in the long term.

3.1 Participants

3.3.1 Recruitment of participants

All people with a first stroke who were admitted to the inpatient unit of the Tung Wah Hospital in Hong Kong were screened as potential subjects. The recruitment of the patients was started in March 2005 and completed in Oct 2006. Informed consent was given by all subjects through methods approved by the university and the hospital's institutional review board (Appendix A). Total 380 patients were screened according to the inclusive and exclusive criteria in the study period. The eligibility was verified in a clinical examination by a physiotherapist before randomization. 76 patients met all the criteria but 22 of them refused to provide informed consent. As a result, a total of 54 patients were selected to proceed in the training study.

3.3.2 Screening for Inclusive/ Exclusive criteria

Patients had to satisfy the six inclusion criteria for this study: (1) diagnosis of ischemic brain injury or intracerebral hemorrhage by magnetic resonance imaging or computed tomography less than 6 weeks after the onset of stroke; (2) premorbid independent outdoor walker; (3) sufficient cognition to follow simple instructions as well as understand the content and purpose of the study (Mini-Mental State Examination score >21) (Tombaugh and McIntyre 1992); (4) ability to stand upright, supported or unsupported, for 1 minute; (5) significant gait deficit (Functional Ambulation Category, or FAC, scale <3) (Collen et al. 1990); and (6) no skin allergy to electrical stimulation.

Patients were excluded if they had (1) a recurrent stroke or other neurological deficit that would affect ambulation ability; (2) any additional medical or psychological condition that would affect their ability to comply with the study protocol, e.g., a significant orthopedic or chronic pain condition, demand cardiac pacemaker placement, newly developed deep vein thrombosis over thigh or calf area; (3) aphasia with inability to follow 2 consecutive step commands, or have a cognitive deficit; or (4) severe hip, knee or ankle contracture that would preclude passive range of motion of the leg.

3.2 Research Design

The study design was a randomized controlled trial of a 4-week intervention with a follow-up after 6 months. Randomization was done by computer-generated random numbers. All subjects were informed consent through methods approved by the university and the hospital's institutional review board. Eligible subjects were assigned to 1 of 3 groups: conventional overground gait training (CT), gait training on an electromechanical gait trainer (GT), or gait training on an electromechanical gait trainer with FES (GT-FES) according to the list of generated random numbers after the baseline assessment. Figure 1 shows the training program details for each group. All subjects received their regular weekday 40-minute physiotherapy sessions and 1.5-hour multidisciplinary treatments, which consisted of occupational therapy, speech therapy, and clinical psychology treatment throughout the study period. All subjects participated in the 4 weeks of training during the study period stayed in the same hospital. They were not recommended to have any kind of alternative medical treatments, e.g. traditional Chinese medicine or acupuncture treatment during this period.

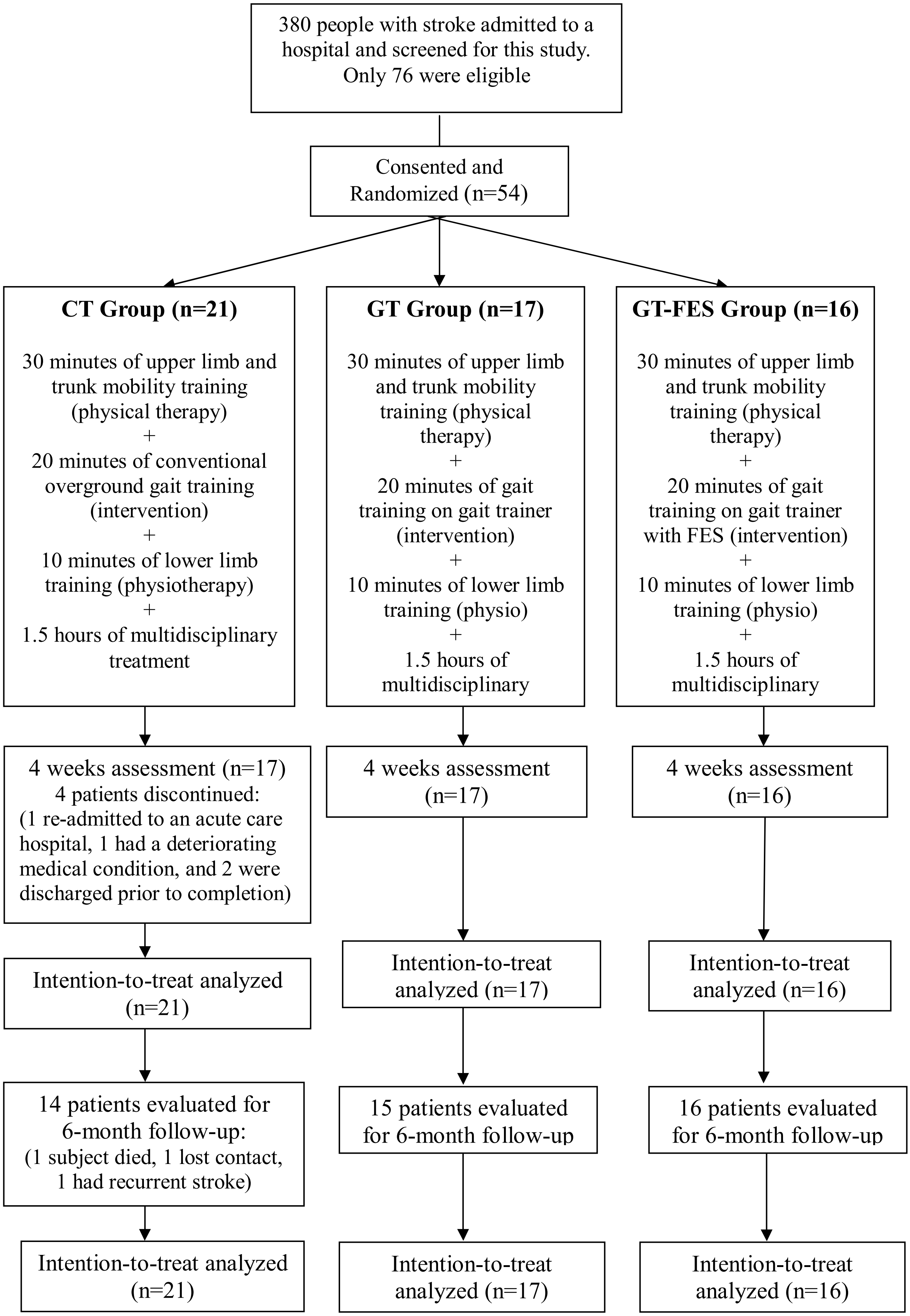

Figure 1. Flowchart of the training programs

3.3 Assessments

3.3.1 Outcome Measures

The demographic data of all subjects including age, gender, side of hemiplegia, etiology of stroke and time post-stroke were recorded before treatment. For outcome measurements, all subjects were evaluated before gait training, at the completion of the 4-week intervention period and at the follow-up 6 months post-training. Patients were assessed by 5 primary outcome measures: Motricity Index, Elderly Mobility Scale, Berg Balance Scale, Functional Ambulatory Category and walking speed as well as 2 secondary outcome measures: Functional independence Measure and Barthel Index. All assessments during the study period, including the screening of patients, as well as the whole training procedure were done by a single research physical therapist at the physical therapy department of the hospital. Neither the patients nor the research physical therapist were blinded to the treatment because it was impractical to do so.

3.3.1.1 Motor strength

The Motricity Index was one of the measurement tools that was used to assess the motor impairment of a patient who had a stroke. The leg subscale of the Motricity Index was chose to evaluate the motor power of lower extremity according to 3 joint movements (hip flexion, knee extension and ankle dorsiflexion). Score: 0 = No movement; 9 = Palpable contraction in muscle but no movement; 14 = Movement seen but not full range/not against gravity; 19 = Full range against gravity, not against resistance; 25 = Movement against resistance but weaker than other side; 33 = Normal power respectively for individual joint movement (Appendix B). Validity and reliability have been proved sensitive to change in recovery after stroke (Demeurisse et al. 1980, Cameron and Bohannon 2000). For individual actions (ankle dorsiflexion, knee extension and hip flexion) and all actions combined, Pearson correlations were good to excellent (r = 0.78–0.91), significant ($p < 0.001$), and of high power (9%) (Cameron and Bohannon 2000). It was used in the current study for analysis of motor loss of the affected lower limb after stroke.

3.3.1.2 Mobility

General mobility independence was assessed by the Elderly Mobility Scale (EMS). The EMS tests the following functions: lying to sitting, sitting to lying, sitting to standing, standing, gait, walking speed and functional reach (Appendix C). It is an assessment of locomotion, balance and key position changes that are prerequisites to more complex activities of daily living (Collen et al. 1990). The maximum possible score, representing independent mobility, is 20 while the minimum score is zero. Concurrent validity was established by correlating the Elderly Mobility Scale (EMS) score with Barthel and functional independence measure (FIM) scores for 36 patients, age 70-93 years. Spearman's ρ was 0.962 with Barthel and 0.948 with FIM -- highly significant correlations. Inter-rater reliability was established on 15 patients who were assessed and there was no significant difference between scores taken by two physiotherapists (Smith 1994). This scale has been further proved to be valid, with good inter-rater reliability that could be readily applied during daily clinical work (Prosser and Canby 1997).

3.3.1.3 Balance

Berg Balance Scale (BBS) assesses ability to maintain balance, either statically or while performing various functional movements. It comprises 14 observable tasks common to everyday life measured on a 5-point ordinal scale, from 0 to 4, according to the patient's performance. Maximum score 56, a higher score reflects better balance; score of 45 required for independent safe ambulation, 0 to 20 considered a poor balance (Appendix D). It has been shown to have excellent inter-rater and intra-rater reliability for elderly subjects (Thorbahn and Newton 1996) and subjects with acute stroke Berg et al. 1989). It has been proved reliable and valid in previous studies (Thorbahn and Newton 1996, Berg et al. 1989) and able to detect change in balance of people with acute stroke (Wood-Dauphinee et al. 1997). This has been shown to have excellent inter-rater and intra-rater reliability for subjects with acute stroke (inter-rater ICC (2,1) = 0.98 and intra-rater ICC(2,1) = 0.97) (Berg et al.1989).

3.3.1.4 Ambulation ability

Ambulatory ability was rated using the Functional Ambulation Category (FAC) scale (Collen et al. 1990). Participants were rated according to the personnel support needed for gait, regardless of use of an assistive device, according to a 6-point scale: 0–5 scale on which 0 describes a patient who cannot walk or requires help of two or more therapists and 5 describes a patient who is ambulatory under all conditions (Appendix E).

3.3.1.5 Gait Speed

Overground walking speed was measured by timing a walk over 5 meters with a stopwatch. The distance of 5 meters was chosen for the walking test as it is relatively short and enables people with relatively poor aerobic fitness, balance or lower-limb strength to complete the walking test more readily

(Cunha TI et al. 2002). The subject walked along a straight line route and two marks were printed on the floor with 5 meters apart. The subject started 2 meters before the first mark and completed a walking trial after the second mark by 2 meters. Time was taken when the subject passed between these two marks. The subject was asked to walk as fast as possible on a walkway for 5 meters using a walking aid if necessary. No other assistance was given and no orthoses were allowed for the walking test. The walking speed was regarded as 0.0 m/s if the subject was unable to finish the whole 5 meters or required manual support for walking. Walking speed was measured in 2 trials, with the mean of the 2 trial speeds recorded as the gait speed of the subject.

3.3.1.6 Activities of daily living

The Functional Independence Measure (FIM) instrument (Keith et al. 1987) and the Barthel Index (BI) (Viosca et al. 2005) were used to provide a comprehensive view of a patient's status in overall functions. FIM measures not only self-care activities and mobility but also communication and cognitive functions. It is an 18-item questionnaire that assesses independence with self-care, bladder/bowel management, transfers, locomotion, communication, and social cognition on a scale of 1-7. The final score ranges between 18 and 126. It is well validated and the inter-rater reliability is high (Hamilton et al. 1994).

The Barthel Index is a validated and widely used instrument to measure dependency in activities of daily life. This index measures mobility, stair climbing, self-care, and incontinence, using a 5-point rating scale ranging from fully independent to unable to perform task (Appendix F). The Barthel Index is a valid and reliable measure that is useful in both acute care and in rehabilitation settings, and it has been widely used throughout the stroke literature. It is sensitive to change and is well documented throughout literature as able to demonstrate both change and progress over time (Viosca et al. 2005). The Barthel Index does not test cognitive function. The FIM and the BI were performed before and at the end of the 4-week intervention period and at the follow-up 6 months later by nurses who were blinded to this study.

3.3.2 Follow-up assessment

All subjects were invited back for follow-up assessment 6 months after the intervention. Subjects were considered as dropped-out if they had a recurrent stroke, lost contact or unavailable to come back. Same outcome measures: Motricity Index for muscle strength, Elderly Mobility Scale for mobility, Berg Balance Scale for balance, Functional Ambulation Category for functional ambulation, walking speed and Functional Independence Measure and Barthel Index for ADL independency were re-assessed during the follow-up session.

3.4 Procedure

3.4.1 Random Assignment to Group

The study design was a randomized controlled trial of a 4-week intervention with a follow-up after 6 months. Randomization was made in accord with a computer-generated random table with 3 sets of random numbers represented the 3 groups. Subjects were assigned to 1 of 3 groups: conventional over-ground gait training treatment (CT), gait training on an electromechanical gait trainer (GT), or gait training on an electromechanical gait trainer with FES

(GT-FES) according to the top of the list of generated random numbers after the baseline assessment.

3.4.2 Treatment Procedure

All subjects in all groups underwent one gait training session of 20 minutes duration per weekday for the 4 weeks under supervision of a physical therapist. In additional to the assigned group treatment, each subject also received his or her own regular hospital-prescribed 40 minutes of physical therapy and a 1.5-hour multidisciplinary treatment session every weekday throughout the 4-week intervention period. A physiotherapy session usually begins with stretching exercises to restore flexibility to tight muscles in the affected side of trunk, arms and legs. Cardiovascular exercises for both arms and legs are used to build endurance and improve circulation. Specific strengthening exercises are also planned for weakened arm, leg and trunk muscles. Activities for daily living such as changing positions from sitting to standing, getting out of bed, walking over ground, slopes or stairs are also parts of the routine rehabilitation training.

The multidisciplinary treatment consisted of a scheduled occupational therapy, speech therapy and psychology multidisciplinary program. To minimize interference from FES by external electrical stimulation on the study's results, no electrical stimulation was applied during the subjects' regular hospital rehabilitation.

3.4.2.1 Gait Trainer Training

Patients in the GT group trained on the electromechanical gait trainer with their body weight partially supported by a harness attached by ropes to a gear system, according to the subject's ability in lifting the paretic foot during the swing phase (Hesse and Uhlenbrock 2000). Walking was simulated by propulsion of the footplates, which aided the movement of the feet and legs in a symmetric manner with a gait cycle ratio of 60-40% between stance and swing phases. The target training velocity was relatively slow (0.20 m/s to 0.60 m/s) to avoid overexertion of the subject. There was partial support of body weight, which was reduced as soon as the subject could support his or her full body weight. The clinical criterion for the reduction was that the subject showed the ability to move his or her hips and was able to support his or her own body weight sufficiently on the affected lower limb and straighten their legs during the single-leg stance phase. Weight support would be gradually decreased by 5kg in each session if the subjects had the above clinical criterion. Gait speed would be gradually increased by 0.1m/sec in next session if the subjects completed the last training session without discomfort. The subject's physical therapist gave assistance during the gait training to help with the subject's knee extension as well as verbal cueing for head and trunk extension and erection and midline awareness. Each gait training session was of 20 minutes duration with an optional rest break (of 1-3 minutes) after the first 10 minutes.

3.4.2.2 Gait Trainer Combined with Functional Electrical Stimulation

Subjects in the GT-FES group underwent the same ambulatory training on the gait trainer as the GT group as well as FES. Subjects in the GT-FES group underwent the same interventions as the GT group, except for the additional feature of functional electrical stimulation during their gait trainer sessions.

A pair of self-adhesive electrodes (model: Platinum Blue 901220, size: 5 x 5 cm square electrode)[§] was attached to the subject's quadriceps in the paretic side and stimulated in the stance phase to facilitate weight acceptance (Figure 2). Another pair of electrodes (model: Ultraflex 881150, size: 3.8 mm round electrode) was attached to the subject's common peroneal nerve in the paretic side and stimulated during the swing phase to generate ankle dorsiflexion and knee flexion (Figure 3). The stimulation sites were determined beforehand, with the subject in a seated position and when a correct functional response was obtained, i.e., the knee extended when the quadriceps were stimulated and the ankle dorsiflexed when the peroneal nerve was stimulated. Stimulation intensity was then raised until the functional movement over the desired range of motion (knee angle less than 20 degrees from the full extension; ankle angle in neural or dorsiflexed position) was achieved with comfort for the subject, then the sites were marked on the skin with nonconductive, semi-permanent ink. Electrodes would then be attached to the same marked sites throughout the 4-week intervention period. Before each subject's first training session, intermittent stimulation was tested continuously on the subject for at least 10 minutes in order to rule out skin allergy contraindication.

Each subject received electrical stimulation modalities, including waveform and pulse width with fixed values. The stimulation intensity was adjusted by the supervising physical therapist according to how successful the correct limb movement was elicited and to the subject's comfort threshold (Table 2). Two connection wires linked the gait trainer control box and the two single-channel FES stimulators. Once the gait trainer switched on, it would automatically synchronize the gait phase and the stimulation timing for the quadriceps and the common peroneal nerve. Each GT-FES subject received standardized electrical stimulation modalities, including waveform and pulse width with fixed values (rectangular pulse with pulse width of 400μs with rising edge and falling edge ramp set as 0.3 s). The subject's quadriceps in the paretic side were stimulated in the stance phase to facilitate weight acceptance, and his or her common peroneal nerve in the paretic side was stimulated during the swing phase to elicit ankle dorsiflexion and knee flexion. Figure 4 showed one participant was training in the gait trainer with two pairs of electrodes attached to the paretic limb.

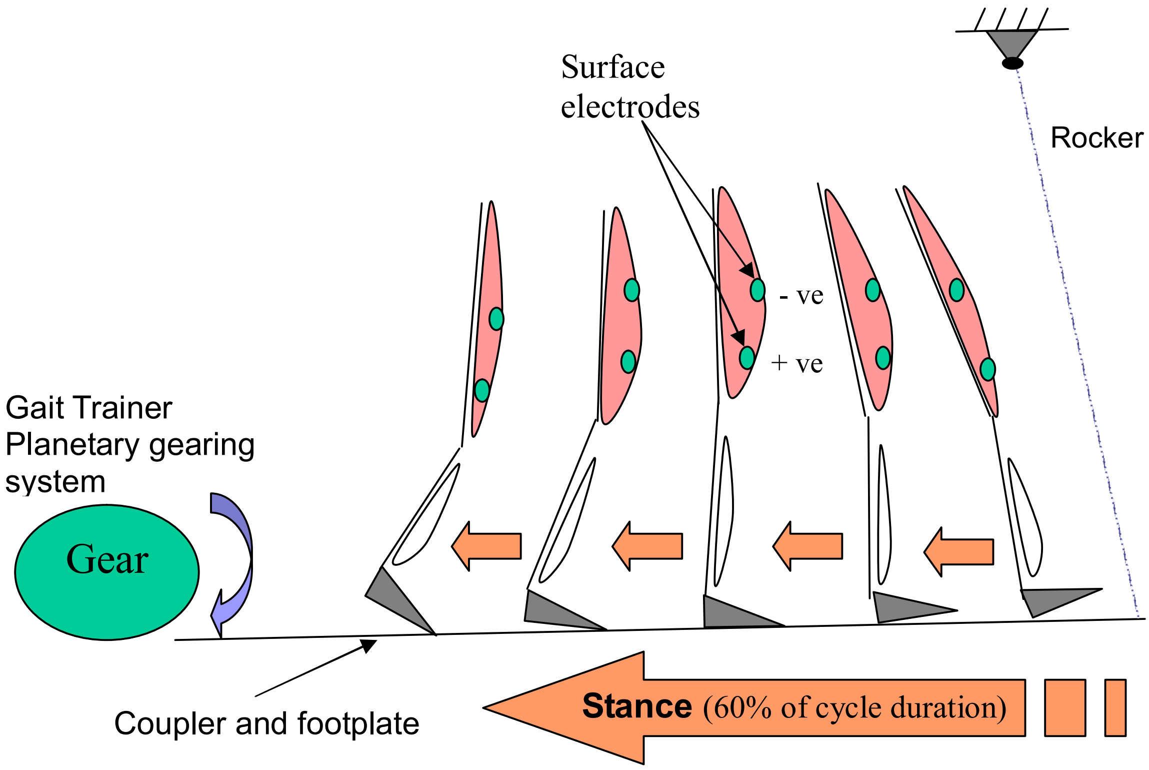

Figure 2. Position of paretic leg (sagittal plane) on the gait trainer footplate during a stance phase. The colored muscle is the quadriceps femoris muscle that is stimulated to enhance knee extension and weight acceptance during the stance phase. The electrical stimulation timing synchronized with the gait cycle of the gait trainer.

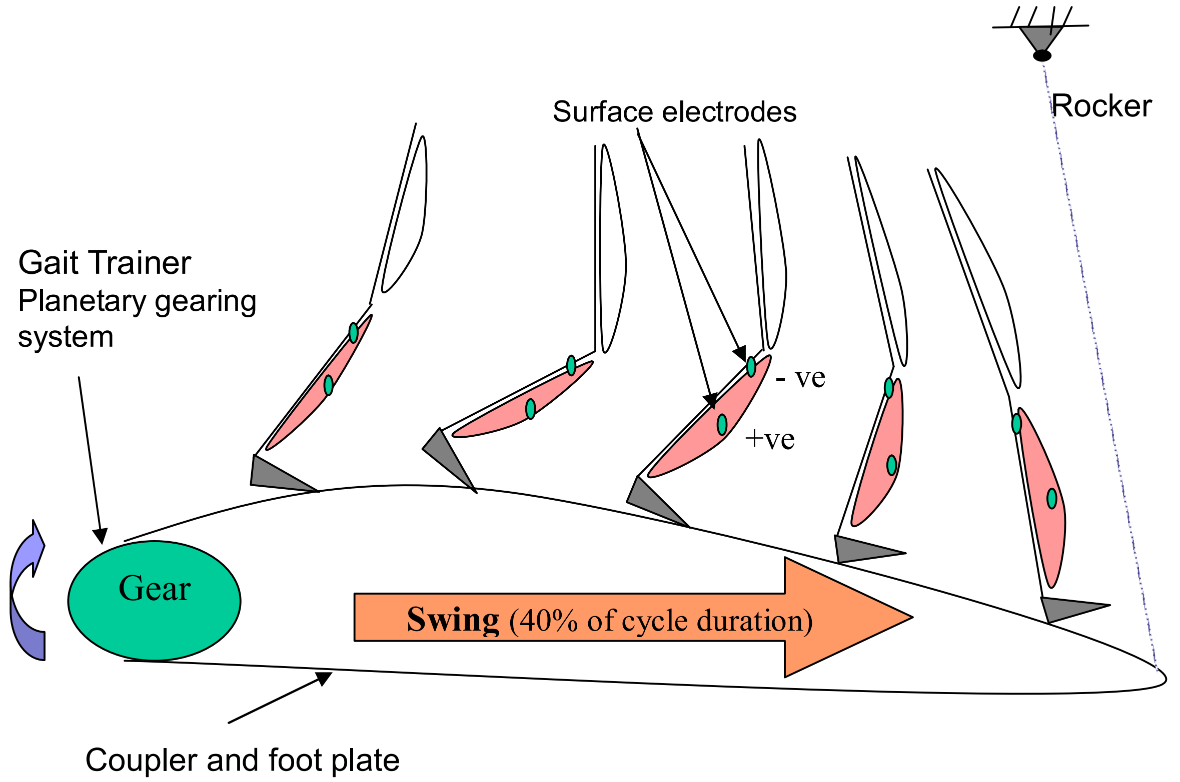

Figure 3. Position of paretic leg (sagittal plane) on the gait trainer foot plate during a swing phase. During the swing phase, the common peroneal nerve is stimulated and the colored muscle is the tibialis anterior muscle is activated. Ankle dorsiflexion and knee flexion was generated in order to prevent foot drip during leg swing. The electrical stimulation timing synchronized with the gait cycle of the gait trainer.

Figure 4. A patient walking on the gait trainer. Two FES devices were applied on the paretic side to assist knee extension during stance phase and elicit the ankle dorsiflexion in swing phase alternatively. Stimulation sites and parameters were set before the first session of training and fixed for each session of training.

3.4.2.3 Conventional Gait Training

The CT group received conventional physical-therapy gait training based on the principles of proprioceptive neuromuscular facilitation and Bobath concepts (Ada et al. 2003, Cunha IT et al. 2001). The principle of the Bobath treatment is to train up the key proximal segments then distal segments in order to improve the subject's posture and movement (Bobath 1978). Bobath therapists intended to inhibit an increased muscle tone by gently mobilizing paretic limbs and opposing synergistic movements and to repeat quasi in short form the statomotoric development of a child as prerequisite for a final goal of a most natural walking habit. Accordingly, tone-inhibiting maneuvers and motor tasks while lying, sitting or standing dominated therapy sessions of patients, who desperately wished to walk.

Each gait training session was conducted by the subject's own hospital physical therapist who was blinded to the group assignments. Each session of physical therapy was documented, with each type of activity and its duration recorded.

3.5 Statistical Analysis

SPSS (version 14.0) was used in statistical analyses in this study. Descriptive statistics and pre-training outcome variables of age, time since onset of stroke, and gait speed were compared using one-way analysis of variance (ANOVA), while gender, diagnosis (ischemic or hemorrhagic), side of the hemiparesis, ordinal variables (MI, EMS, BBS, FAC) were compared using the Kruskal-Wallis test. Intention-to-treat analysis was used for all of the subjects. Data that were missing owing to subjects being dropped from the study were replaced by the last scores obtained.

Multivariate analysis of covariance (MANCOVA) incorporating all outcome measures recorded in all time intervals was used to test the overall effect of the assigned interventions and to reduce the probability of type I error owing to multiple comparisons (Tabachnick 1996). The within-subject factor was set as time and the between-subject factor was set as group. The baseline measurement of each respective outcome and demographic data were entered as the covariate. If the MANCOVA revealed a significant effect, post hoc analysis using univariate 2-way analysis of covariance (ANCOVA) was used to indicate which particular measurement time showed significant difference between particular groups.

To explore the strength of relationship and practical significance of group differences, effect size (ES) was calculated ($ES = Mean_{Group1} - Mean_{Group2} / SD_{pooled}$). The established criteria of the ES, which reflects the effect of a treatment within a population of interest, are small (<0.41), medium (0.41-0.70), or large (>0.70) (Hidler and Wall 2005). An alpha level of $p<0.05$ was assumed to be significant and the Tukey significant difference test was then used for post hoc comparison.

Chapter 4

RESULTS

4.1 Participant Demographics

A total of 380 hemiplegic patients from a first stroke who were admitted to the hospital in-patient setting for rehabilitation were screened for this study during the recruitment period. Fifty four of them fulfilled the inclusion criteria and agreed to join the study as subjects. They were randomly assigned to 1 of the 3 gait training groups (CT: n=21, GT: n=17, GT-FES: n=16).

Table 1 shows the characteristics and the pre-training scores of all the subjects. The GT-FES group had the youngest mean age while the CT group was relatively older. Most of the subjects were male and were suffered from ischemic stroke mainly. Time post-stroke before entering the study of the subjects was less than 3 weeks. There were no clinically relevant differences between the 3 groups for demographic variables or all outcome measures at baseline.

Four subjects (all from the CT group) out of the 54 subjects admitted to the study did not attend the entire gait training sessions (1 subject was admitted to an acute care hospital, 1 had deteriorating medical condition, and 2 were discharged from the hospital prior to completion of the 4-week intervention period). Five more subjects (3 from the CT group and 2 from the GT group) did not come back for the 6-month follow-up (1 subject had died, 3 had recurrent stroke, and 1 had lost contact).

Table 1. Baseline demographic characteristics of the conventional training (CT), gait trainer (GT) and gait trainer with functional electrical stimulation (GT-FES) groups

	CT Group (n=21)	**GT Group (n=17)**	**GT-FES Group (n=16)**
Age (years)ǂ	73.4 (11.5)	66.6 (11.3)	62.0 (10.0)
Gender (male/female)	13 /8	11/6	10/5
Etiology (ischemic/hemorrhagic)	18/3	13/4	11/4
Side of hemiplegia (right/left)	8/13	8/9	6/9
Time post-stroke before recruitmentǂ (weeks)	2.5 (1.2)	2.7 (1.2)	2.3 (1.1)

ǂValues: mean (standard deviation)

4.2 Training variables

The mean gait trainer initial training speed for the GT group was 0.11 ± 0.06 (SD) meters per second (m/s), while for the GT-FES group it was 0.17 ± 0.04 m/s. Training speed was relatively slow because of the fair exercise tolerance and endurance of the patients in the subacute phase of stroke. The mean speeds gradually increased to 0.39 ± 0.11 m/s for both groups by the end of the 4-week intervention period.

Body weight support for the GT group was initially at 25% ± 7.2% and gradually decreased to 0.5% ± 0.9% by the end of the 4 weeks. For the GT-FES group, body weight support began at 20% ± 6.3%; most of the GT-FES subjects (70%) could walk without any body weight support after the 16th gait training session. With the help of the electrical stimulation, subjects trained with GT+FES were able to accept weight and have more proper weight shifting to the affected side probably. Most of the subjects in the GT and GT-FES groups completed all gait training sessions; from those 2 groups, a total of 6 subjects required 1 or 2 rest breaks during the sessions. Adverse side effects during the training and overexertion of the subjects did not occur.

Table 2. Comparison of pre-training, post-training and follow-up outcome measures

	Group	Pre-training	Post-training (4 weeks)	Follow-up (6 months)	*P*	Post hoc (*P*) [Effect size]
MI	CT	51.6±13.1	68.4±18.7	73.1±20.8	0.107	/
	GT	52.3±21.2	74.7±22.1	81.1±20.8		
	GT-FES	46.8±20.3	69.6±20.1	80.5±19.0		
EMS	CT	6.3±4.0	12.4±6.0	13.3±6.2	0.005*	**4 weeks:** CT vs GT (0.017*)[0.90] CT vs GT-FES (0.016*)[0.87] GT vs GT-FES (0.997)[0.005] **6 months:** CT vs GT (0.024*)[0.86] CT vs GT-FES (0.006*)[1.14] GT vs GT-FES (0.846)[0.31]
	GT	6.7±3.0	16.9±3.0	17.6±3.0		
	GT-FES	6.6±3.2	16.9±3.0	18.6±2.0		
BBS	CT	13.1±9.1	28.5±15.9	36.5±15.0	0.170	/
	GT	13.8±9.4	37.1±9.6	43.5±10.3		
	GT-FES	15.4±11.3	37.8±12.8	46.0±10.0		
FAC	CT	1.4±0.7	2.5±1.2	3.0±1.3	0.008*	**4 weeks:** CT vs GT (0.096)[0.67] CT vs GT-FES (0.024*)[0.78] GT vs GT-FES (0.819)[0.20] **6 months:** CT vs GT (0.018*)[0.88] CT vs GT-FES (0.003*)[1.13] GT vs GT-FES (0.766)[0.24]
	GT	1.3±0.9	3.2±0.8	4.0±1.0		
	GT-FES	1.3±0.5	3.5±0.9	4.2±0.8		
Gait Speed	CT	0.0±0.01	0.19±0.26	0.30±0.34	<0.0001*	**4 weeks:** CT vs GT (0.027*)[1.03] CT vs GT-FES (<0.0001*) [1.24] GT vs GT-FES (0.245)[0.53] **6 months:** CT vs GT (0.006*)[1.09] CT vs GT-FES (0.004*)[1.17] GT vs GT-FES (0.984)[0.09]
	GT	0.0±0.05	0.43±0.21	0.66±0.30		
	GT-FES	0.0±0.0	0.60±0.40	0.69±0.32		
BI	CT	53.3±12.4	76.3±19.3	80.8±19.2	0.913	/
	GT	54.4±13.5	79.1±19.4	83.8±16.2		
	GT-FES	46..4±13.6	73.6±19.0	80.7±14.9		
FIM	CT	78.6±8.9	98.2±14.3	102.5±16.5	0.598	/
	GT	78.6±12.0	103.2±17.6	107.2±15.1		
	GT-FES	65.0±16.8	86.4±20.5	94.0±20.2		

Values: mean ± standard deviation; P value: significance level of MANCOVA;
*Indicates significant differences were revealed; post hoc specify the effect of group difference.

4.3 Descriptive analysis of dependent variables

4.3.1 Post-4-week intervention effect

Subjects in all of the groups showed significant improvement in mobility, ambulation ability, walking speed and lower limb strength after the 4 weeks of gait training. All subjects could walk faster and more independently along the training period. They also performed better in daily functional activities than before entering the study. The results for all outcomes before training, 4 weeks post training as well as 6 months follow up sessions are presented in Table 2. Further comparison between the groups was done in effect size calculations.

MANCOVA with baseline values of individual outcomes as covariates showed significant time by group interaction in 3 out of the 7 outcome measures: EMS (Wilks' Lambda=0.743, P=0.005), FAC (Wilks' Lambda=0.744, P=0.005), and gait speed (Wilks' Lambda=0.658, P<0.0001). While in Motricity Index, Berg balance scale, and the two ADL independence measurements (FIM and BI), no significant differences were found between the 3 groups.

4.3.1.1 Motricity Index

Motricity Index leg subscore measured hip flexion, knee extension and ankle dorsiflexion strength of subjects. All the groups showed significant improvement in lower leg strength along the training period (Fig 5). Whatever what kind of gait training method received, patients had significant motor return during the subacute phase of stroke. Although both the GT and GT-FES groups averaged Motricity Index scores that were higher than the CT group, these differences were not statistically significant (p = 0.107) after 4 weeks of training.

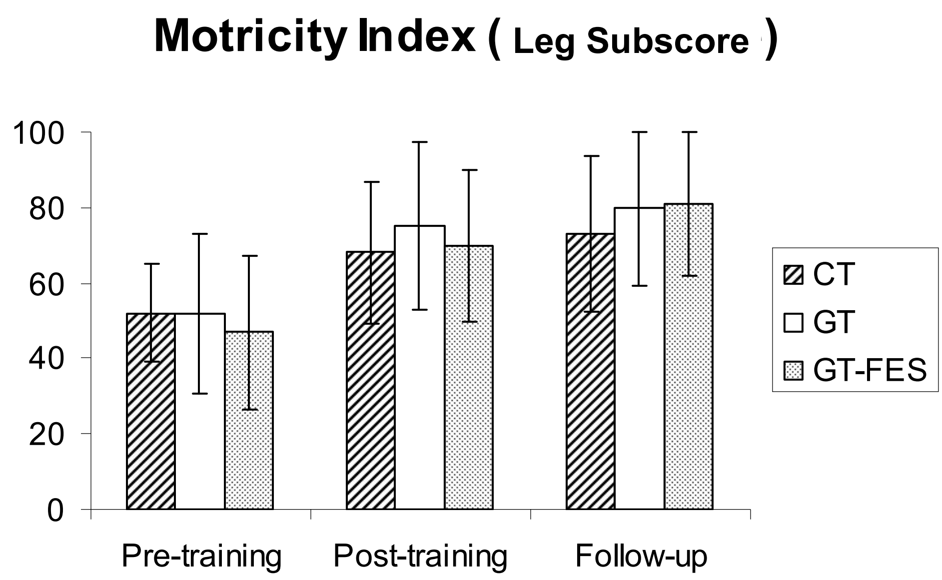

Figure 5. Histogram of mean MI score with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had significant improvement of motor strength along the time but no significantly difference was found among the three groups.

4.3.1.2 Elderly Mobility Scale

EMS measured the mobility of subjects including the bed mobility, transfer, sitting to standing, mode of gait, walking speed and functional reach. All subjects had significantly better mobility after 4 weeks of training (Fig 6). Average EMS score of GT and GT-FES groups were higher than CT group. Post hoc analysis (univariate 2-way ANCOVA) revealed significantly better improvement in the two gait trainer groups than the CT group [GT vs CT (p = 0.017); GT-FES vs CT (p = 0.016)] immediately after the 4 weeks of training.

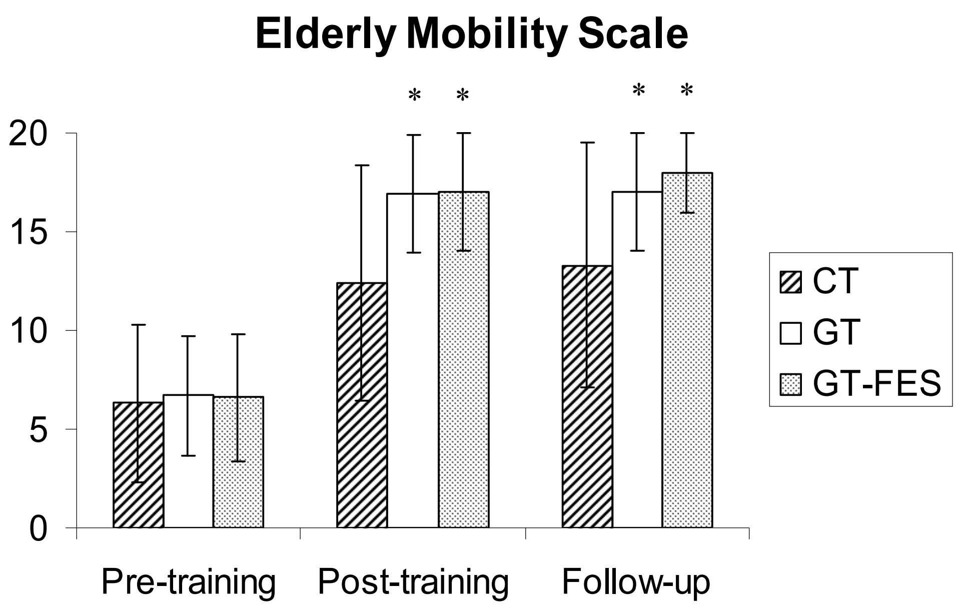

Figure 6. Histogram of mean EMS score with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had significant improvement of mobility along the time while GT and GT-FES groups increased significantly when compared with CT group at post-training and follow-up time period.

4.3.1.3 Berg Balance Scale

BBS measured the ability of subjects to keep balance in different static and dynamic conditions, postures and base support. All the groups showed significant improvement in balance along the training period (Fig 7). Whatever what kind of gait training method received, patients gained better balance control during the subacute phase of stroke. Although both the GT and GT-FES groups averaged BBS scores that were higher than the CT group, these differences were not statistically significant (*p* = 0.17) after 4 weeks of training.

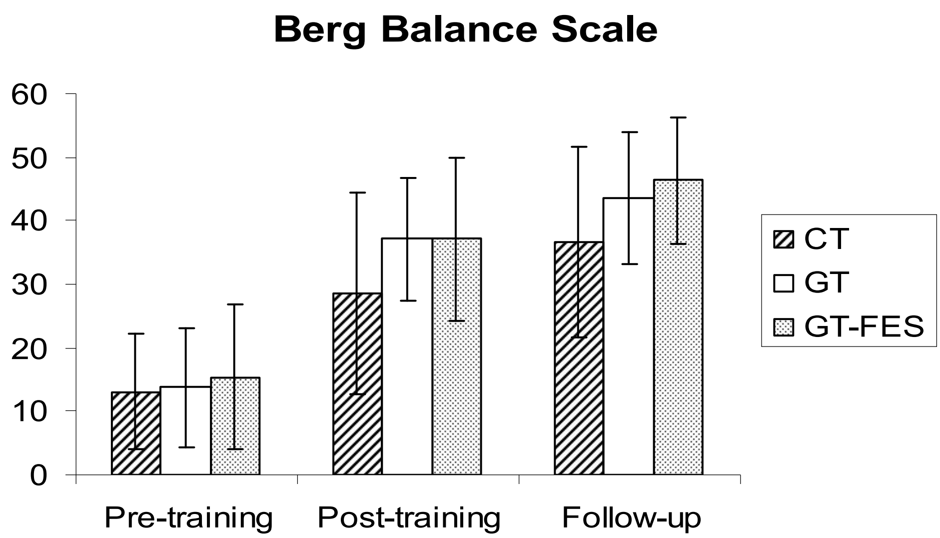

Figure 7. Histogram of mean BBS score with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had significant improvement of balance along the time but no significantly difference was found among the three groups.

4.3.1.4 Functional Ambulatory Category

FAC indicated the ability and independency of subjects in walking. All subjects could walk significantly more independent and needed less assistance on overground walking, slope or stairs walking after 4 weeks of training (Fig 8). Average FAC score of GT and GT-FES groups were higher than CT group. Post hoc analysis (univariate 2-way ANCOVA) revealed only the GT-FES group showed significantly higher ambulation independency (FAC) than the CT group. Seven out of the 16 subjects (43.8%) in the GT-FES group could walk independently with verbal supervision at least, with FAC>=4 at the end of the 4 weeks of training. Only 5 out of the 17 subjects (29.4%) in the GT group and 6 out of the 21 subjects (28.6%) in the CT group who finished the 4 weeks of intervention reached this level.

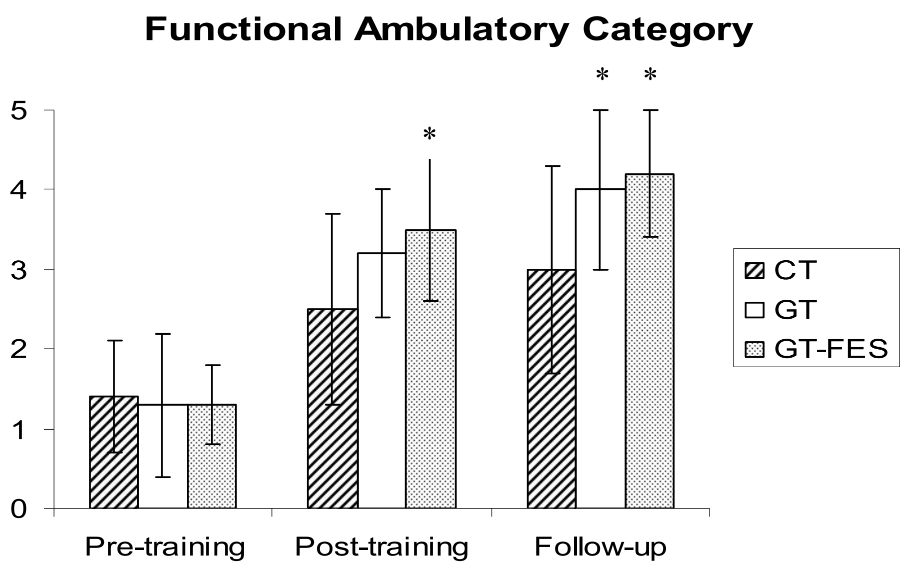

Figure 8. Histogram of mean FAC score with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had significant improvement of ambulation ability along the time. Only GT-FES groups increased significantly when compared with CT group post-training.

4.3.1.5 Gait Speed

The walking speed of subjects was measured by timing the velocity walking on level ground for 5 meters. All subjects could walk significantly faster with or without aid after 4 weeks of training (Fig 9). Average walking velocity of GT and GT-FES groups were significantly higher than CT group after 4 weeks of gait training. Post hoc analysis (univariate 2-way ANCOVA) revealed significantly better improvement in the two gait trainer groups than the CT group [GT vs CT (p = 0.027); GT-FES vs CT ($p < 0.0001$)] immediately after the 4 weeks of training.

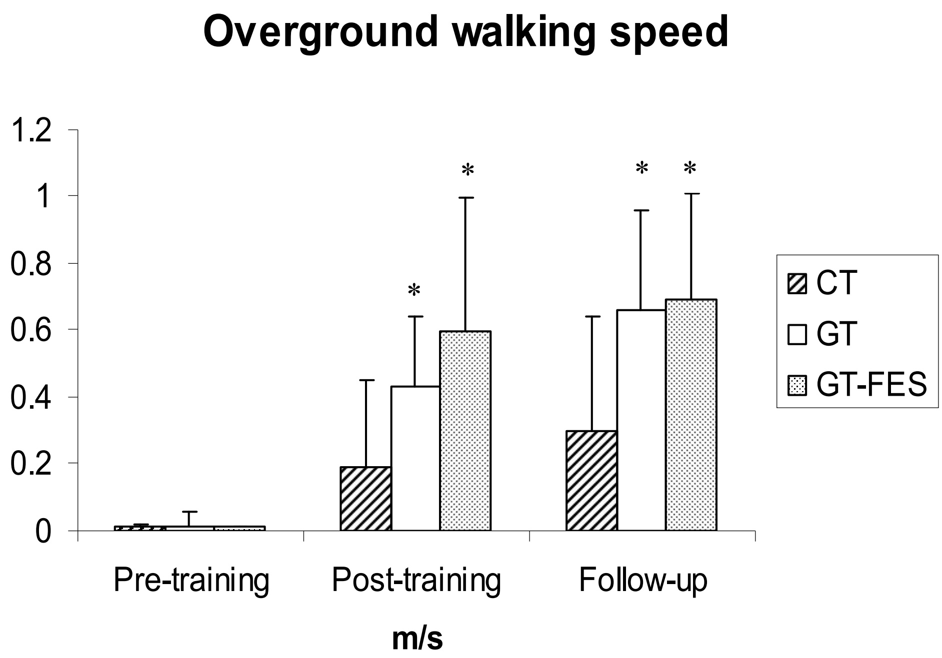

Figure 9. Histogram of mean gait speed with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had significant improvement of walking speed along the time while GT and GT-FES groups increased significantly when compared with CT group at post-training and follow-up time period.

4.3.1.6 Barthel Index and Functional Independency Measure

FIM and BI measured the ADL independency including bowel or bladder control, hygiene, feeding, dressing, bathing, transfer and ambulatory ability. These scores reflected the ability of self-caring in gross spectrum of daily activities. FIM and BI scores kept steady improvement of all groups along the rehabilitation period of stroke (Fig 10 & 11). No significant difference was found between all groups.

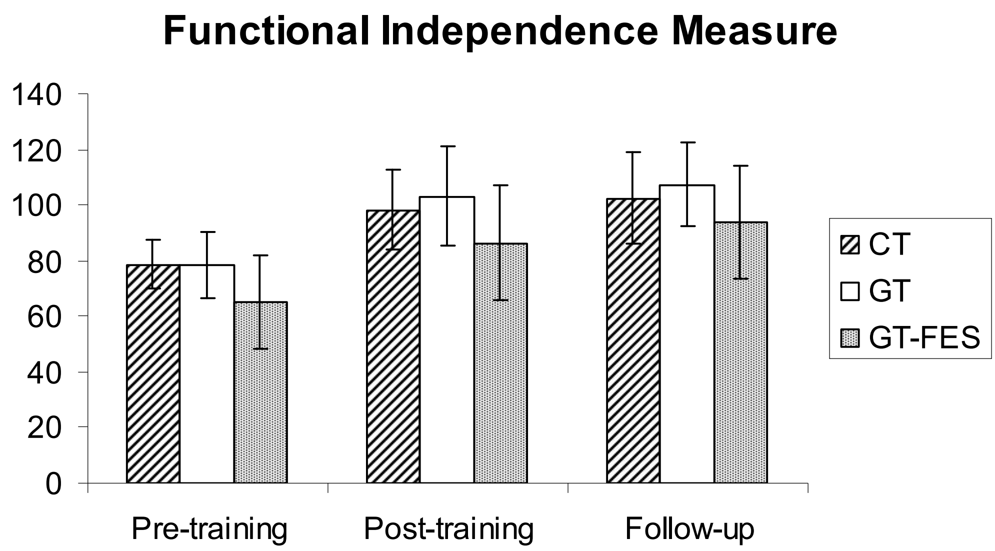

Figure 10. Histogram of mean FIM socre with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had improvement of functional independence along the time but no significantly difference was found among the three groups.

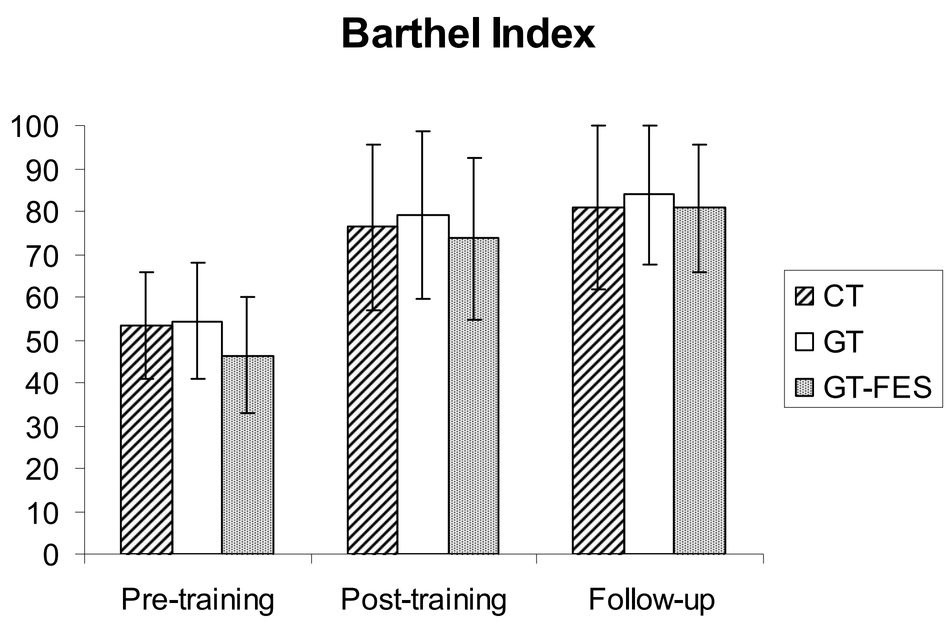

Figure 11. Histogram of mean BI socre with variations of time and treatment protocols. Standard deviations were indicated as vertical bars. This figure shows that all three groups of subjects had improvement of functional performance along the time but no significantly difference was found among the three groups.

4.3.2 Follow-up after 6 months

To assess any long-term effect, all outcomes of the study were re-assessed 6 months after the 4-week intervention period ended. A total of 45 subjects (CT: n=14; GT: n=15; GT-FES: n=16) came back 6 months after their gait training for a follow-up assessment. All the 45 subjects had received non-study-related outpatient rehabilitation at the same hospital for 3 to 4 weeks (3 sessions a week, with each session lasting 3 hours) after their discharge from the hospital. Five of them (1 from CT, 2 from GT and 2 from GT-FES) also had received private acupuncture treatment (mean: 8 weeks, SD: 3.5 weeks), while 7 of them (3 from CT, 3 from GT and 1 from GT-FES) received private physical therapy treatment (mean: 4 weeks, SD: 2.8 weeks) after the outpatient rehabilitation.

All the 3 groups showed continued improvement after the completion of the 4-week intervention. In between-group comparisons, both the GT and GT-FES groups showed a higher level of mobility, gait independence and velocity than the CT group in the follow-up assessment (Table 2). Post hoc analysis (univariate 2-way ANCOVA) revealed that both the GT and GT-FES groups had significantly more improvements in EMS (GT vs CT: P=0.024; GT-FES vs CT: P=0.006), FAC (GT vs CT: P=0.018; GT-FES vs CT: P=0.003) and gait speed (GT vs CT: P=0.006; GT-FES vs CT: P=0.004) than the CT group. Thirteen of the 16 patients (81.3%) in the GT-FES group could walk independently with FAC>=4 at the 6-month follow-up. Only 9 out of the original 21 subjects (42.9%) in the CT group and 11 of the original 17 (64.7%) in the GT group reached this level.

Chapter 5

DISCUSSION

Subjects in all 3 groups showed improvement in terms of lower limb strength, mobility, ambulation ability, walking speed, and activities in daily living as the 4-week intervention period progressed. The training effects were significantly greater in the GT and GT-FES groups than in the CT group. Subjects in the GT and GT-FES groups improved significantly in mobility score (EMS), walking speed and FAC than subjects in the CT group except for FAC (GT vs CT) post-4-week intervention.

5.1 Subjects

5.1.1 Demographic characteristics

The average age of all subjects was 67 years old while the average age of the GT-FES group was the youngest and the CT group was the oldest. The CT group was older (73 yr versus 62 yr) than the GT-FES. There was no significant difference between the mean ages of 3 groups. However, the age of subjects was set as a covariate in MANCOVA analysis. The possible effect of the potential difference caused by the age difference was issued. Over 60% of the subjects with stroke were male and about 80% of all had ischemic stroke with non-ambulatory hemiplegia. All subjects had no history of recurrent stroke and were independent with all activities of daily living as well as an unaided independent outdoor walker pre-morbidly. Their cognitive conditions were good with score above MMSE 24/30 at admission and were able to understand what would be done in the study.

5.1.2 Observations on participants during the gait training session

Patients could practice highly symmetric fashion gait pattern during gait trainer training without heavy effort on the therapist. Gait trainer could increase the practical chance of non-ambulatory patients during their physiotherapy rehabilitation with up to 1000 walking repetitions per training session.

Although the gait trainer alone helps with the movement of the feet both during stance and swing phases as well as assists weight-shifting with control of the centre of mass, it is unable to provide knee control during weight bearing and ankle dorsiflexion during terminal swing of the paretic limb[24]. With the help of synchronized stimulation from the FES to the knee extensors and ankle dorsiflexors, patients were afforded more practice for managing close-to-normal body weight with the coupled modalities than otherwise possible with gait trainer alone. Less difficult stance phase motor tasks could then be more effectively assisted by FES-induced muscle activations without requirement of continuous manual support by the therapist during the gait trainer training. Several subjects in GT-FES group stated that they enjoyed the gait training on the gait trainer coupled FES by taking advantage of the machine support as well as with FES-induced ankle dorsiflexion during the swing phase of the paretic limb. The swing effort was less and safer as compared with ground level walking.

Participants also reported that they felt more secure and willing to put weight on the paretic limb during single-leg stance with the help of quadriceps electrical stimulation by the FES brought extra strength to their legs. They also received cues from the tingling sensation of FES for the timing of when to straighten their knees or toe-up during the gait cycle and then actively participated in the training process. They could then gain more meaningful and functional therapeutic effect of electrical stimulation instead of passive repetitive stimulation on the paralyzed muscles only during the conventional treatment.

5.2 Outcome Measurement

5.2.1 Post-training immediate effect

All subjects in all 3 groups showed improvement in terms of lower limb strength, mobility, ambulation ability, walking speed, and activities in daily living during the 4-week intervention period. The results of this randomized clinical trial indicated that gait training using the electromechanical gait trainer with and without FES was more effective than conventional overground gait training. In our study, subjects in groups GT and GT-FES improved significantly in EMS, walking speed, muscle strength and FAC than subjects in the CT group.

Effect sizes were calculated for the 3 significant outcome measures (EMS, walking speed and FAC) to see the potential of having a statistically significant effect for the insignificant ones. For the FAC (4 weeks), effect size calculations revealed a medium value in the GT vs CT groups. However, although most of the effect size differences between the GT and GT-FES groups were small, the gait speeds in the 4-week intervention period showed a medium effect size difference, with the GT-FES group more superior for a treatment effect. This suggests that a larger sample size would have possibly produced a more statistically significant effect.

Motor learning and developing walking skills require practice with concrete goals and the patients must have the opportunity to practice actively and to understand the importance of frequent repetitions (Rosebaum 1991). This theory was indicated by the result of this study that only the outcome measure tools (FAC, walking speed) specially measuring the gait ability trained by gait trainer showed significantly better improvement than the control group. While for ADL measurement, the improvement was not significant because no intensive training was given during this study period.

During our intervention, the gait trainer provided symmetrical removal of weight from the lower extremities, integrated weight bearing, provided stepping and balance and stimulated repetitive and rhythmic stepping. Also the weight bearing of the lower limbs was controlled and a gradual increase in weight bearing was achieved. Although the propulsion of the gait trainer alone helped with the movement of the feet both during stance and swing as well as assists weight-shifting with control of the centre of mass, the gait trainer is unable to provide knee control during weight bearing and ankle dorsiflexion during terminal swing of the paretic limb (Werner et al. 2002). A more perfect gait pattern is generated by this combination of the two existing rehabilitation equipments with the electrical stimulation support to the weak knee extensors by the FES. Only GT-FES group showed significant better score in FAC than CT group reflected that the possibility of this more perfect gait pattern during training could enhance the independency in walking after training.

5.2.2 Follow-up

The findings of this study showed clinical significance that the an intensive 4-week electromechanical gait trainer training fastened locomotor recovery following stroke in subacute phase and maintained their improved ambulatory ability up to 6 months after cessation of training. All groups were able to make continued improvement in all outcome measures in the 6-month interval after the end of the 4-week training period. Improvement in all variables was found across time with an interaction between time and the variables. Significant carryover effect was illustrated by faster gait speed, higher EMS mobility score as well as better functional ambulatory status measured in two treatment groups than the control after 6 months of the training. We can see that patients who treated with gait trainer with or without FES could live with a more independent functional status after discharge than others who did not received this additional form of intervention. This better ability enabled the patients in GT or GT-FES group to participate more in normal daily activities and could further enhance them to gain more opportunities to walk more than home bound patients. As a result, it could improve the quality of life after stroke.

This finding suggests the subjects were able to build on their interventions, regardless of the kind of gait training they underwent in the 4 weeks, to make continual gains in gross motor and gait improvement even after the gait training had ended. Of course, one could not eliminate the change may due to natural recovery or spontaneous recovery during these period without interventions.

5.3 Comparison with other studies

The design of our study were comparable to the study of Peurala et al. (2005), who studied people with chronic stroke (post-stroke >2 years) undergoing a 20-minute training session every weekday for 3 weeks. Their results did not show any difference in performance between subjects who were assigned to conventional overground gait training and those who used a gait trainer with or without FES. At the 6-month follow-up in their study, they found that all of the gait characteristics remained. In our study, in contrast, the subjects in the GT and GT-FES groups not only walked significantly faster than those in the CT group during the 4-week intervention period, the 6-month follow-up also showed continued improvements in all 3 groups. The difference between the findings in the Peurala et al. (2005) study and this study might owe to the fact that the subjects in Peurala et al.'s study were in a chronic phase of stroke and therefore many of them might not have been severely impaired in walking. This may further implied that the longer the delay of intensive gait training begin after stroke, the lesser the effect of the gait trainer might be shown.

Many studies (De Quervain et al. 1996, Olney et al. 1998, Mulroy et al. 2003) have reported that improvement in gait ability mainly occurred during the first few months after stroke and that a time lag before a stroke patient underwent gait rehabilitation might have furthered deterioration in gait ability of the patient. Recent studies show a strong and consistent negative association between the time from stroke symptom onset to the commencement of rehabilitation and functional outcomes (Mulroy et al. 2003). The results of the current study provided evidence that the BWS electromechanical gait trainer, which could be used for early rehabilitation after stroke onset, could significantly shorten the ambulation dependence time when compared with conventional gait training.

Supportive study results from Pohl et al. (2006) also showed patients with subacute stroke trained with electromechanical gait trainer (GT I) gained superior ambulatory ability than whom trained only by conventional physiotherapy only. Following random group allocation, patients in the experimental group (Group A) practiced 20 min of gait training on the GT I and 25 min of physiotherapy (PT) and patients in the control group (Group B) practiced 45 min of PT 5 days a week for 4 weeks. The PT in both groups concentrated on gait practice on the floor and stairs. Gait ability, assessed by the Functional Ambulation Category (FAC) (0–5 scale, and competence in basic activities of living (Barthel Index, 0–100) were the primary blindly assessed variables. Both groups had homogeneous clinical data at study onset. Group A patients scored significantly higher at the end of the study and at follow-up on both primary outcome parameters. At the end of the study, 41 of 77 (53.2%) in Group A versus 17 of 77 (22.1%) in Group B could walk independently. This large multi-center trial with 155 non-ambulatory stroke patients revealed a superior gait ability and competence in basic activities of living in the experimental group. Group A patients practiced 800 to 1,200 steps each session on the machine, while Group B patients rarely exceeded 200 steps during their individual 45 min PT sessions. Accordingly, the known positive correlation between treatment intensity and motor outcome most likely explained the superior treatment result.

Reports from Waters et al (1985) Burridge et al (1997) stated that there was a short-lasting or long-lasting 'carry-over' effect after using FES. It was proposed that FES potentially provided an artificial way of ensuring synchronized pre-synaptic and post-synaptic activity in the affected population of anterior horn cells, as long as FES is coupled with simultaneous voluntary effort by the subject, so that the combination would activate the residual pyramidal tract (Shik et al. 1969). In other words, FES might improve the fitness and strength of the paralyzed motor units of people with stroke who still have voluntary control. Hesse et al (1995b) found that a combined therapy of treadmill gait training and FES produced a positive training effect compared with a single kind of either treadmill training or FES therapy. The improvement in outcome measures in the GT and GT-FES groups in our study were similar and no significant differences were found. Although a gait trainer helps with the movement of the feet and legs during the stance and swing phases as well with assisting in weight shifting by increasing the stability of the center of mass, a gait trainer is unable to provide knee control during weight bearing, ankle dorsiflexion and knee flexion during the swing phase of the paretic limb (Hesse and Uhlenbrock 2000). The stance phase motor tasks could therefore be more effectively assisted by FES-induced muscle activations, which also reduce the need for continuous manual guidance by a physical therapist during the gait trainer exercise. GT-FES subjects also reported they were willing to put weight on the paretic limb as they felt that the induced contraction by the FES brought extra strength to the leg during the single-leg stance phase. During the training, GT-FES group had less mean body weight support and faster mean walking speed than the GT group during gait trainer training sessions. Moreover, they also received cues from the tingling sensation of FES in when to straighten their knee and flex their knee during a gait cycle, which encouraged them to actively participate in the training process. By doing so, they could gain a more meaningful and functional therapeutic effect from electrical stimulation instead of passively letting their paralyzed muscles be stimulated electrically during conventional treatment in a seated position.

When compared with another kind of robotic device for gait rehabilitation, Husemann and co-workers conducted a randomized, controlled study of 30 acute stroke survivors (Husemann et al 2007). The treatment group received 30 minutes of daily robotic training using Lokomat and the control group 30 minutes of conventional physiotherapy daily in addition to 30 minutes of conventional physiotherapy for each group. After 4 weeks of therapy, the walking ability of the Lokomat group and the control group expressed as the functional ambulation classification was significantly improved. However, there was no significant difference in gain of these parameters between the groups. The possible difference between the finding of Lokomat and our study on the electromechanical gait trainer would be the degree of passive driven limb movement during walking on the machine. Training by the Lokomat is mainly automatic including assisted hip, knee ad ankle movement while gait trainer provides higher degree of active participation or control of weight bearing and joint movement as well as weight shifting during walking. The study Lokomat by Hidler and Wall (2005) stated that limiting the degrees of freedom the person is allowed to move with the device caused a decrease in muscle activation (EMG) patterns than in normal walking.

5.4 Clinical significance

Gait rehabilitation for people with stroke should be goal-directed. The BWS electromechanical gait trainer provided active simulation of stance and swing phases in a physiologic manner. The body weight of subjects was partially supported to compensate for the paresis of the affected lower limb. This was considered one of the major advantages of using a BWS system for early rehabilitation, in that a subject's body weight could be supported as needed to help the subject establish an upright position for taking steps while also providing task-specific, repetitive walking training (Visintin et al. 1998). Nevertheless, it should be noted that there are differences in the activation patterns of some muscles during mechanically assisted walking compared with a natural gait.

Our findings showed clinical significance for an intensive 4-week intervention that used an electromechanical gait trainer for accelerating locomotor recovery in patients following stroke in the subacute phase and maintaining an improved ambulatory ability up to 6 months after the completion of the intervention. Both gait trainer interventions helped patients after stroke to attain a higher level of ambulatory independence and functional mobility score and hence shortened the time of disability. Our current study involved gait training of patients before they could even stand independently owing to weak trunk and proximal limb control. This approach is different from the conventional Bobath therapeutic approach, which advocates training of proximal stability before distal mobility (Bobath 1978). This may imply that such a dependent walker after stroke may have a better chance of becoming more independent even after discharge from the hospital.

In our study, FES was used to stimulate the quadriceps and the common peroneal nerve in subjects in the GT-FES group. Results revealed that the effect sizes of GT-FES group versus CT group in EMS, FAC and walking speed at the end of the 4 weeks and follow up were all higher than the GT group versus CT group. This may indicate that FES combined with GT could improve mobility, walking independency and walking speed more effectively than GT alone or conventional gait training.

This study is the first step in investigating interaction between two known-to-be effective therapeutic modalities for persons recovering from stroke, in a targeted intervention. It is essential the clinician, given the limitations of our current health care system, to choose and explore alternative forms of training that are effective in more than one area of the disablement for this patient population.

5.5 Limitation of study and recommendations for future studies

All of the outcome measures except for the FIM and BI, were scored by an unblinded therapist. This is one of the major problems with the study, and could have introduced bias. The assessor was unblinded because she was also the treating therapist in the study. This is truly unfavorable and a main limitation in our study due to practical resource problem. Another limitation in this study is the possible effect of the age difference found between the 3 groups. Although there was no statistical significance difference found between the 3 groups on baseline comparison, CT group had 11 years older than GT-FES group in terms of mean age values. This uncontrolled variable was set as a covariate in MANCOVA analysis in order to issue the potential effect on the dependent variables. So as to dilute the baseline demographic characteristics difference and solve other limitation problems, a larger scale and blinded randomized controlled trial will be recommended in the future based on this pilot study.

For the result, although no significant difference was found between the 2 treatment groups, effect size calculation showed more superior treatment effect of GT-FES group than GT groups. This suggested that a larger sample size would have possibly produced a more statistically significant effect between these two experimental groups. In this study, small sample size might not generate enough power to detect significant differences. However, increasing sample size involves tangible costs, both in time, money, and effort. Therefore, it should be carefully decided to make sample size "large enough," but not wastefully large. We did a sample size estimation using a 0.8 power level after recruiting 30 subjects. At least 50-60 subjects were needed in order to show significance difference among groups. Future research should utilize a reasonable larger sample size may help in detect any further clinically important differences between gait trainer groups with and without FES in stroke rehabilitation.

Another reason why no significant differences were found between the two experimental groups might be an insufficient number of stimulation sites on each subject in the GT-FES group. A study by Daly et al (1996) showed that the more muscles stimulated by intramuscular electrodes, the better the improvement in gait. More paretic muscle groups (e.g., plantarflexors, knee flexors and hip extensors) could be stimulated using intramuscular electrodes in GT-FES groups in future studies. In this study, only 2 simulation sites were chosen for subjects in the GT-FES group, therefore further studies in the future could investigate more and different simulation sites and patterns.

Chapter 6

CONCLUSIONS

Subjects who underwent 4 weeks of gait training using an electromechanical gait trainer alone or combined with functional electrical stimulation were found to display significantly improvement in mobility, functional ambulation and walking speed when compared with subjects who underwent conventional overground gait training and continue to carry over 6 month after the stop of intervention. A body weight-supported system could enable nonambulatory people with subacute stroke to receive more effective, early intensive gait training. Although no significant difference was found between the 2 treatment groups, the effect size calculation showed more superior treatment effect of GT-FES group than GT groups. Both gait trainer interventions helped patients after stroke to attain a higher level of ambulatory independence and functional mobility score and hence shortened the time of disability.

We can see that patients who treated with gait trainer with or without FES could live with a more independent functional status after discharge than others who did not received this additional form of intervention. This better ability enabled them to participate more in normal daily activities and could further gain more opportunities to walk more than home bound patients. As a result, it could improve the quality of life after stroke. There could be a benefit from shifting the rehabilitation paradigm from neurodevelopmental therapy to task-specific training, with the electromechanical gait trainer being one of a number of strategies that could be used.

Appendix A

Consent Form

I, __________________ (name of subject), hereby consent to participate in, as a subject, in "The effects of electromechanical gait trainer cyclic walking exercise alone or combined with Functional Electrical Stimulation (FES) for patients with acute stroke".

1 I have understood the experimental procedures presented to me.
2 I have given an opportunity to ask questions about the experiment, and these have been answered to my satisfaction.
3 I realize I can discontinue the experiment with no reasons given and no penalty received during the experiment.
4 I realize that the results of this experiment may be published, but that my own results will be kept confidential.
5 I realize that the results of this experiment are the properties of the Hong Kong Polytechnic University

Subject name:_____________________

Signature:_____________________

Witness:_________________________

Signature:_____________________

Date:___________________________

Appendix B

Motricity Index

Score	
0	No movement
9	Palpable contraction in muscle but no movement
14	Movement seen but not full range/not against gravity
19	Full range against gravity, not against resistance
25	Movement against resistance but weaker than other side
33	Normal power respectively for individual joint movement

Leg subscale score = Hip flexion + Knee extension + ankle dorsiflexion score +1

Appendix C

Elderly Mobility Scale

Lying to Sitting	2 1 0	Independent Supervision or help of 1 person Help of 2 or more persons
Sitting to Lying	2 1 0	Independent Supervision or help of 1 person Help of 2 or more persons
Sitting to Standing	3 2 1 0	Independent in 3 sec or less Independent in more than 3 sec Supervision or help of 1 person Help of 2 or more persons
Standing Balance	3 2 1 0	Stands without support and can lift arms reach forward Stands without support but requires support to reach forward Stands with support Stands with physical help by another person
Gait	3 2 1 0	Independent including the use of stick or crutch Independent with walking frame or 2 sticks/ crutches Walks with or without walking aid but erratic/ unsafe turning Requires physical help to walk or constant supervision
Timed walk (6 meters)	3 2 1 0	15 sec or less 16-30 sec Over 30 sec Unable to cover 6 meters
Functional reach	4 2 0	Over 20 cm 10-20 cm Under 10 cm or unable
Total score		

Appendix D

Berg Balance Scale

Test	Test Instruction	Scoring Instruction	Admission / /	Discharge / /
Sitting to Standing	Please stand up. Try not to use your hands for support	able to stand, no hands & stabilize **independently;** able to stand independently **using hands;** able to stand using hands after **several trials;** needs **minimal assistance** to stand or stabilize; needs **moderate or maximal assistance** to stand	4 3 2 1 0	4 3 2 1 0
Standing unsupported	Stand for 2 min without hold. If subject able to stand for 2 min safely. score full marks for sitting unsupported. Proceed to pos change standing to sitting.	able to stand safely **2 mins;** able to stand **2 mins with supervision;** able to stand **30 secs unsupported;** needs **several tries** to stand 30 secs unsupported; unable to 30 secs unassisted	4 3 2 1 0	4 3 2 1 0
Sitting unsupported feet on floor	Sit with arms folded for 2 minutes.	able to sit safely and securely **2 mins;** able to sit **2 mins under supervision;** able to sit **30 secs;** able to sit **10 secs;** unable to sit without support 10 secs	4 3 2 1 0	4 3 2 1 0
Standing to Sitting	Please sit down	sits safely with **minimal use of hands;** controls descent by **using hands;** uses back of **legs against chair** to control descent; sits independent but has **uncontrolled descent;** needs assistance to sit	4 3 2 1 0	4 3 2 1 0
Transfers	Please move from chair to bed and back again; one transfer with a seat with armrests and one transfer without armrests.	able to transfer safely with **minor use of hands;** able to transfer safely **definite need** use of **hands;** able to transfer with **verbal cuing** and/or **supervision;** needs **one person** to assist; needs **two people** to assist or supervise to be safe.	4 3 2 1 0	4 3 2 1 0
Standing unsupported with eyes closed	Close your eyes and stand still for 10 seconds.	able to **stand 10 secs** safely; able to stand **10 secs** with **supervision;** able to stand **3 secs** **unable** to **keep eyes closed 3 secs** but stays steady; needs help to keep from falling;	4 3 2 1 0	4 3 2 1 0
Standing unsupported with feet together	Place your feet together and stand without holding.	able to place feet together indept & st for **1 min** safely; able to place ft together indept & st for 1 min with **supervision;** able to place ft together indept but ≠ **hold for 30 secs;** need help to attain pos but able to **st 15 sec ft together** need help to attain position & unable to hold 15sec	4 3 2 1 0	4 3 2 1 0
Reach fwd with out stretched arm	Lift arm to 90.Stretch out your fingers and reach forward as far as you can.	can reach forward confidently > **10 inches;** can reach forward > **5 inches** safely; can reach forward > **2 inches** safely; reaches forward but needs **supervision;** needs help to keep from falling	4 3 2 1 0	4 3 2 1 0
Picked up object from the floor	Pick up shoes/slipper placed in frnot of feet	able to pick up slippers safely & easily able to pick up slippers but needs **supervision** unable to pick up but reach **1-2inch from** slipper & **keep balance** unable to pick up & need **supervision** while trying unable to try ; needs assistance to keep from falling	4 3 2 1 0	4 3 2 1 0
Turning to look behind over L & R shoulders	Turn to look behind you toward left shoulder. Repeat to the right.	Look behind from **both sides** and weight shifts well; looks behind **one side** only, other side shows less weight shift; **turn sideways** only but maintain balance; needs **supervision** when **turning;** needs assistance to keep from falling	4 3 2 1 0	4 3 2 1 0
Turning 360	Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.	able to turn 360safely in < **4 secs each side;** able to turn 360safely **one side** only < 4 secs; able to turn 360safely but **slowly;** needs **close supervision** or **verbal cuing;** needs assistance while turning	4 3 2 1 0	4 3 2 1 0
Placing alt foot on stool (Dynamic wt shift in unsupp st	Place each foot alternately on the stool. Continue until each foot has touched the stool four times.	able to stand indept and safely and complete **8 steps in 20 secs;** able to stand independently in and complete **8 steps > 20 secs;** able to complete **4 steps** without aid with supervision; able to complete **> 2 steps** needs **minimal assistance;** needs assistance to keep from falling/ unable to try	4 3 2 1 0	4 3 2 1 0
Standing unsupported foot in front (Demonstrate to subject)	Place one foot in front of the other. If you feel that you can't place your foot directly in front, try to step far enough ahead that the hl of your fwd foot fs ahead of the toes of the other.	able to place foot **tandem** independently and **hold 30 secs;** able to place foot **ahead** of other independently and **hold 30 secs;** able t6 take **small steps** independently and **hold 30 secs;** needs help to step but can **hold 15 secs;** losses balance while stepping or standing	4 3 2 1 0	4 3 2 1 0
Standing on one leg	Stand on one leg as long as you can without holding.	able to lift leg independently and **hold > 10 secs;** able to lift leg independently and **hold 5-10 secs;** able to lift leg independently and **hold ≥3 secs;** tries to lift leg, unable to hold 3 secs but remains **st independently;** unable to try or needs **assistance** to prevent fall	4 3 2 1 0	4 3 2 1 0
		Total Score		

Appendix E

Functional Ambulation Categories

0	Cannot walk or requires help of two or more people
1	Requires firm continuous support from one person in walking
2	Requires continuous or intermittent support of one person in walking
3	Requires verbal supervision or standby help from one person in walking
4	Transfer, turn and walk independently on level ground but requires help on stairs, slopes or uneven surfaces
5	Independent walker

Appendix F

BARTHEL INDEX *(Shah et al, 1989)*	**Date** / /				
Bowel Control (0 = incontinent; 2 = needs help to assess appropriate position; 5 = can assure appropriate position, frequent accidents; 8 = supervision, occasional accidents; 10 = continent)	0	2	5	8	10
Bladder Control (0 = incontinent / catheterized; 2 = incontinent but able to assist with internal / external device; 5 = generally dry by day, not at night; 8 = occasional accident; 10 = continent)	0	2	5	8	10
Personal Hygiene (0 = unable; 1 = needs assistance in all steps; 3 = moderate help (1 or more steps); 4 = minimal help; 5 = independent face / hair / teeth / shaving)	0	1	3	4	5
Toilet (0 = dependent; 2 = needs assistant in all aspects; 5 = needs some help (clothes, transfer, hand washing); 8 = supervision; 10 = independent)	0	2	5	8	10
Feeding (0 = dependent; 2 = can manipulate spoon, but needs active assistance during meal; 5 = needs supervision, needs some help (set up activities); 8 = independent in feeding, need help in cut meat, open jar lid etc.; 10 = independent)	0	2	5	8	10
Dressing (0 = dependent; 2 = needs assistance in most aspects; 5 = needs assistance in pulling on / removing clothes; 8 = minimal assistance in fasting clothes (buttons, zips, shoes, bra etc.); 10 = independent)	0	2	5	8	10
Bathing (0 = dependent; 1 = needs assistant in all steps; 3 = needs assistant in transfer / washing / drying; 4 = supervision (water temperature / transfer); 5 = independent)	0	1	3	4	5
Bed / Chair Transfer (0 = unable; 3 = maximum assistance; 8 = some assistance; 12 = supervision; 15 = independent)	0	3	8	12	15
Ambulation (0 = dependent; 3 = moderate to maximum assistance; 8 = some assistance; 12 = independent, < 50 M; 15 = independent, > 50 M)	0	3	8	12	15
OR Wheelchair (0 = dependent; 1 = propel self for short distance, mostly needs assistance; 3 = can propel, but needs assistance in transfer; 4 = propels for reasonable duration, occasionally needs assistance; 5 = independent, > 50 M)	0	1	3	4	5
Stairs (0 = unable; 2 = needs assistant in all aspects; 5 = minimal assistance; 8 = supervision; 10 = independent (walking aids / handrail))	0	2	5	8	10
Total (0 – 100)	/ 100				

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