WALKING AFTER STROKE

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Stroke is the leading cause of adult disability and inpatient rehabilitation admissions (1,2). Approximately 400/100 000 persons over the age of 45 years have a first stroke each year in the United States, Europe, and Australia (3). According to International Stroke Trial reports, at 6 months after stroke, about 20% are dead, 50% are independent and 30% are dependent in self-care (4). In Turkey, the annual incidence rate of stroke is 167 per 100 000 population (5). Fatality rate is 19.7% during the first month and 37 to 57% are discharged from neurology clinics with severe impairments (6). Dependence in mobility is one of the primary reasons of admission for inpatient rehabilitation after stroke. Much effort goes into helping these patients regain the ability to walk at least in the home prior to discharge. In spite of these efforts, approximately 35% of survivors with initial paralysis of the leg do not regain useful walking function, and 25% of all survivors are unable to walk without full physical assistance (7).

Characteristics of hemiparetic gait

Stroke patients exhibit varying deficits in perception, muscle strength, motor control, passive mobility, sensation, tone and balance (8-16). These impairments have significant effects upon walking ability. The exact combination of the impairments depends on the extensiveness and location of the brain damage. Other factors that might influence the level of limitation in walking activity are learning ability, coping skills, motivation, medical co-morbidities, physical endurance levels, family support, housing and the amount and type of rehabilitation training (13,14). Even patients with functional ambulation display very different gait patterns compared with able-bodied persons thus increasing the risk of falling. Marked variation in gait patterns across stroke patients has also been noted (16).

Hemiparetic gait is characterized by slow and asymmetric steps with poor selective motor control, delayed and disrupted equilibrium reactions and reduced weight bearing on the paretic limb (12,14-18). Smooth and symmetric forward progression of the body is impaired with a large variation in gait patterns related to the degree of recovery (19). Well-controlled intra-limb and inter-limb coordination is replaced by mass limb movement patterns (synergies) on the paretic side requiring compensatory adjustments of the pelvis and non-paretic side. Compensatory movements necessary for ambulation produce abnormal displacement of the center of gravity, resulting in increased energy expenditure (20).

Previous stroke studies have reported altered kinematic and kinetic gait profile in both magnitude (peak and valley angle, moment and power), and pattern (shape and direction of curves) indicating an impaired ability to generate and grade the forces that control limb movement (10,16,20-23). Hemiparetic gait is often characterized by stiff-legged gait (reduced range of knee motion) and drop foot (lack of ankle dorsiflexion during swing) leading to raised hip during swing. Kim and Eng investigated gait characteristics of 20 chronic community-dwelling stroke patients and concluded that stroke patients use different strategies to achieve the goal of walking (23). Their findings did

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not show a relationship between gait pattern and walking velocity and did not support the goal of "normalization" of movement patterns in management of stroke patients. A cause-effect relationship between impairments of stroke and gait pattern can not yet be determined in order to guide training programs.

Postural control

Postural control has been defined as the act of maintaining, achieving or restoring a state of balance during any posture or activity (24). As well as problems with moving and controlling limbs, many hemiparetic patients also experience difficulty in maintaining balance, because a defect in the "body image" causes them to ignore the affected side. They suffer from severe postural instability and postural asymmetry during quiet standing in the frontal and sagittal planes (25). They present an asymmetrical pattern of lateral movements and greater excursions of the pelvis (excessive excursion of the center of gravity) than healthy subjects walking at similar speeds (26). The accelerations are asymmetrical, with the highest values occurring when weight bearing is on the paretic side. This suggests difficulties in controlling the lateral motion of the trunk segment, which might be very important for maintaining balance in locomotor activities. Impaired balance is often related to uneven weight bearing, increased energy expenditure and may be associated with laterally directed falls and a high risk of fractures in these subjects (27,28).

Gait symmetry

Asymmetric steps are a characteristic of hemiparetic gait, with the paretic limb having a shorter stance time and step length than that of the non-paretic limb. It has been reported that the degree of asymmetry is related to the degree of motor recovery (17,29) and spasticity of the affected ankle plantarflexors (30). Abnormalities in standing balance and asymmetry during single-limb stance are assumed to be related to a decreased ability to bear weight on the hemiplegic side (30). The weight shift to the paretic side is essential in walking as it allows the non-paretic limb to be moved and, consequently, a step to be taken. The ability to maintain single-limb support is an important determinant of gait stability (22). Thus, single-support stability training helps to achieve more symmetric gait in stroke patients with hemiparesis (21). Gait asymmetry leads to increased energy expenditure and risk of falls. Consequently, improvement in symmetry provides an important clinical marker of recovery and functionality (21,22,30,31).

Selective motor control

Stroke patients with poor selective motor control walk with synergistic mass patterns of the affected lower leg rather than isolated joint movements. Simultaneous activation of the quadriceps with the gluteus maximus causes a mass extension pattern during the stance phase. The mass flexion pattern then causes synergistic contraction of the hip flexors, knee flexors, and ankle dorsiflexors during the swing phase (32). This primitive motor control produces the primitive patterned limb movement and inhibits normal progression during walking. It has been suggested that treatment strategies for stroke patients with poor motor control should focus on isolated and selected joint movement training to break up the mass synergistic pattern and improve walking pattern (32). Isolated ankle dorsiflexion while hip and knee are in extension is the first sign of selective motor control after stroke.

Treatment of hemiparetic gait

Treatment for a stroke begins immediately in the hospital with acute care, helping the patient to survive and avoid another similar attack. The next step, spontaneous recovery, happens naturally to most patients due to resolution of edema or reperfusion of the ischemic penumbra. Much of the recovery after the initial two weeks is likely due to brain plasticity (33). Functional reorganization of sensory and motor systems is well documented after stroke (34-36). Regaining lost sensory and motor abilities usually happens during the first few weeks of recovery, but steady progress can take place over a longer period of time. Recovery mechanisms may include unmasking of pre-existing connections, activity-dependent synaptic changes, sprouting of new axon terminals and formation of new synapses (35). Functional neuroimaging studies showed that reorganization is enhanced by rehabilitation programs after stroke (36). There is strong evidence that stroke patients benefit from early organized multidisciplinary care (37) and exercise programs in which functional tasks are directly and intensively trained (38). Organized multidisciplinary care is characterized by early mobilization and multidisciplinary rehabilitation (including physiotherapy) co-ordinated by regular team meetings (39). It has been shown that functional specificity and the progressive complexity of tasks being trained are the key variables of motor training and cortical reorganization (40,41).

The goal of a stroke rehabilitation program is to regain the ability to function and return to a productive and satisfying life. Rehabilitation can achieve these goals by either restoring body functions, by compensation for any body dysfunction, or by combination of both (42). Walking ability is one of the most important functions because independent ambulation is essential for community reintegration and social participation. Thus, gait training accounts for a large proportion of time spent in stroke rehabilitation. Any limitation in an activity may be due to impairments in different body functions, so that specific training to restore impaired body functions will have the highest chance to improve activity levels. If body functions cannot be regained, various orthoses and aids are prescribed for substitution and compensation of lost body functions. Bipedal walking requires harmonization of three basic body functions: 1) maintenance of balance and upright posture of the upper body; 2) cyclical movement of lower extremities; and 3) generation of propulsive forces (43). So, restoration of normal movements of the trunk, pelvis, and lower extremity while walking, improving symmetry and weight bearing on the paretic side, and to establish an energy-efficient walk are the most important goals of gait training in stroke patients (17,18).

Tailor-made physiotherapy is an important part of rehabilitation after stroke. A number of physiotherapy approaches have been developed based on different ideas about how people recover after a stroke. Central to these are approaches based on 'neurophysiologic' principles, 'motor learning' principles and 'orthopedic' principles. However there is no evidence that any one approach was clearly better than another at improving leg strength, balance, walking speed or the ability to perform everyday tasks (24).

Pre-ambulation programs are used to improve strength, coordination, and range of motion, facilitate proprioceptive feedback, develop postural stability, develop controlled mobility in movement transitions and develop dynamic balance control and skills. Parallel bar activities consist of moving from sitting to standing, standing balance and weight-shifting activities, hip-hiking, standing push-ups, stepping forward and backward, forward progression, and use of assistive device with appropriate gait pattern (24). Another way to address postural control deficits is to provide the individual with feedback from a force platform while balance activities are performed (44).

Facilitation of various weight bearing muscles by therapists (45), visual and auditory feedback of patients' weight distribution (46), backward walking (31) and musical motor feedback (47) are used to restore gait symmetry, whereas shoe wedges and lifts are used to compensate gait asymmetry after stroke (48). Lennon et al. (49) reported the beneficial effects of physiotherapy based on the Bobath concept of the weight bearing ability of the hemiplegic side. They attributed the results to improvement in the compensating ability of the non-paretic side after a mean of 17 weeks of outpatient therapy. The Bobath concept aims at the normalization of tone, facilitation of more normal movement patterns as well as the act of walking to improve walking ability in stroke patients (50).

Many techniques are used in the attempt to help the stroke patient regain selective motor control of the affected limbs. Controlled outcome studies have failed to establish the superiority of one technique over another (24). Being the general aim of a neurodevelopmental technique, therapists aim for restoration of a more physiological gait pattern (51). If the patient is unable to initiate movement after stroke, effective strategies may include direct facilitation of movement using extereoceptive, proprioceptive and reflex stimulation techniques, superimposed upon the patients' own attempts to control their body movements. Treatment should involve the patient using the hemiplegic side in volitional motor tasks. The more the patient can be made to use the affected side, the greater the chance of increased sensory awareness and function. The presentation of repeated sensory stimuli will maximize use of residual sensory function and CNS reorganization. Stretch, stroking superficial and deep pressure and weight bearing with approximation can all be used during therapy to increase sensory output. Constraint-induced movement therapy (52), bilateral training (53), motor imagery (54), use of a mirror (55,56), mental practice (57), electromyographic (EMG) biofeedback (58,59), robot-assisted therapy (60), functional vibratory stimulation (61), acupuncture (62) and electrical stimulation (63) techniques are used for muscle re-education and facilitation to re-establish voluntary control of body positions and movements after stroke.

Ankle dorsiflexor muscle strength of the affected side was reported to be the primary determinant for gait velocity and temporal asymmetry (64). Buurke et al. investigated the muscle co-ordination of stroke patients longitudinally and reported that the only changes were in tibialis anterior and gastrocemius muscles (65). In a meta-analysis of eight studies, Moreland et al concluded that EMG biofeedback is superior to conventional therapy alone for improving ankle dorsiflexion muscle strength (59).

Quantitative analysis of hemiparetic gait

Walking ability can be evaluated qualitatively or quantitatively by using various clinical and laboratory tests. Many studies on the recovery of hemiparetic gait have used ordinal functional assessment scales such as the Rivermead Mobility Index, the Barthel Index, the Functional Independence Measure, the Functional Ambulation Categories, and the Timed Up-and-Go Test in which gait is categorized into 3-7 categories according to the distance, time and need for help. Although these scales are easy to apply and affordable, more challenging and nominal tests are needed to detect further improvements due to their ceiling effects for ambulatory stroke patients66. They were designed to measure only basic activities and, as such, do not capture patients' performances in more advanced participation activities.

The most widely used qualitative method to measure walking ability after stroke is walking velocity (38,67). It has been reported as a reliable (68) and responsive predictor of functional status (69,70). Although walking velocity is a useful overall gait measure, it is not adequate to evaluate full gait pattern. Walking velocity is influenced by many factors, ranging from primary impairments of stroke (lack of selective motor control and poor balance) to secondary, compensating contribution of the non-paretic side and trunk (71). Changes in walking velocity may even be a behavioral adaptation to the individual's perceived limits of stability (72). Moreover, the protocols used to measure walking velocity vary considerably between studies (walking short versus long distances, at fast versus self-selected speeds) (73).

Quantitative gait analysis is the best way to understand the complex multifactorial gait dysfunction of hemiparetic patients (14,74). It helps to identify deviations from normal gait, to determine functional problems, to formulate a treatment plan that will bring quantifiable results, and to follow the outcome of the treatment (75,76). Gait can be quantified by time-distance measures, kinematics, kinetics and electromyography. Data may offer suggestions for clinical intervention (77). Buurke et al. reported that muscle activation pattern do not change over time after stroke (65). However, kinematic and kinetic characteristics of gait differ according to the level of motor recovery and time since injury. It has been shown that practice of close-to-normal movements, muscle activation driving practice of movement and repetition of desired movements are effective in the reacquisition of coordinated and skilled movement after stroke (78).

Four groups of gait pattern numbered I to IV, in order of increasing severity, has been defined for children with spastic hemiplegia (79). Such grouping helps building treatment algorithms for children with cerebral palsy however, it is not clear whether same classification is valid for adult hemiplegic patients. Moreover, in a recent study it was concluded that exact agreement was unacceptable for some gait patterns using those groupings, so that kinematic data from 3D instrumented gait analysis and video should be used together when using the grouping scales.

Postural control is most commonly evaluated by force platform systems in terms of postural sway (increased displacement of center-of-mass (COM) within the base of support), symmetry (amount of weight on each side) and limits-of-stability measures (80). It has been shown that postural sway in the frontal plane is specific for the postural control (81) and responsive to balance training after stroke (82). Force platform systems (posturography) are designed to provide visual or auditory feedback to patients regarding the locus of their COM or center-of-pressure (COP), as well as training protocols to enhance postural control. Posturographic data are also used as an outcome parameter to assess the effectiveness of the treatment. However, in controlled trials, if the control group has not received balance training by posturography, the experimental group has the advantage of experience with the system and may get higher scores in the post-treatment assessment. In order to avoid this 'learning effect', it is not advisable to use the same system for both treatment and assessment.

Quantitative gait analysis systems are the best alternative to posturography to assess postural control via the COM path (pelvic excursions in sagittal, coronal and transverse planes) and symmetry in weight bearing. Control of pelvic motion is critical to the maintenance of total body balance since the weight of the head, arms and trunk acts downward through the pelvis. Kinematic and kinetic studies of upper-body motion in the frontal plane have shown that the trunk is precisely controlled and highly dependent upon the motion of the pelvis (83).

To quantify the extent of the temporal and spatial asymmetry of gait pattern, symmetry deviations (unaffected side-affected side, expressed as a fraction of the stride duration) (47), symmetric index (dividing the absolute difference of unaffected and affected by their average) (84) or asymmetry ratios (1-(affected/unaffected)) (30,64) can be calculated. Step length, single support time and percentage of stance phases of the paretic and non-paretic sides are the most frequently compared parameters. Goldie et al (85) reported that increase in single support time on the paretic side is a good indicator of increase in weight bearing on the paretic side, whereas increase in single support time on the non-paretic side is a good indicator of better paretic leg advancement. They pointed that if the goal of treatment is to increase gait velocity and to improve gait pattern, treatment strategies should be directed toward reducing non-paretic single support time. By focusing only on increasing affected single support time, a more symmetrical gait pattern may be achieved, but velocity is likely to decrease. Lin et al (64) investigated the gait symmetry of 68 chronic ambulatory stroke patients and reported dorsiflexor strength of the paretic side to be the primary determinant of temporal gait symmetry.

Haart et al (82) reported that assessment of weight-shifting capacity provides unique information about balance recovery after stroke and can be used as an outcome parameter to develop new rehabilitation strategies. Eng et al (86) have shown that weight bearing ability can be reliably measured by force plates in terms of vertical ground reaction forces and used as an outcome measure in stroke patients. The amount of pelvic excursion in the frontal plane is also reported to reflect the variability in weight bearing on each leg during the single support phase (87).

Selective ankle dorsiflexion represents good motor control after stroke. Ankle dorsiflexion has been used to assess the supraspinal sensorimotor network for the neural motor control of walking (88). Besides qualitative and quantitative clinical assessments, ankle joint rotation angles in the sagittal plane during the gait cycle can also be measured using quantitative gait analysis systems, as well.

In conclusion, the resultant hemiparetic gait pattern following stroke is a mixture of deviations as well as the compensatory motion dictated by residual functions, so that each patient must be examined, and his own unique gait pattern must be identified and documented. tailor-made interventions that specifically target and measure restoration of normal gait pattern after stroke may be more efficacious.

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