CHAPTER II
LITERATURE REVIEW

This chapter reviews literatures relating to the study. The contents are divided into spinal cord injury (SCI), clinical factors influencing ambulatory potential, ambulatory assistive devices, walking capacity assessments following SCI. Details of each topic are as follows;

1. Spinal cord injury: definition, causes, severity and incidence

Spinal cord injury (SCI) can be occurred as a result of traumatic or a non-traumatic causes that disrupts of the neural pathways in the spinal canal and is characterized by muscle weakness, loss of sensation and autonomic dysfunction below the level of the lesion (Haisma, 2008). Traumatic causes can be a direct or indirect effect of a trauma and injury such as road traffic or sport accident (van Asbeck et al., 2000). A non-traumatic SCI can be caused by diseases or disorders that affect functions of the spinal cord such as metastasis, infection, spinal hemorrhage or infarction (American Spinal Injury Association, 2000; New et al., 2002). The extent of neurological deficits depends largely on the level and severity of the lesion. A complete lesion results in total loss of motor and sensory functions in the lowest sacral segment, whereas an incomplete lesion, and partially alters functions of the systems below levels of the lesion (Maynard, et al., 1997).

The American Spinal Injury Association (ASIA) (2000) delicately defined severities of SCI as so-called ASIA impairment Scale (AIS) using following categories;

- A - Complete: No sensory or motor function is preserved in the sacral segments S4-S5
- B - Incomplete: Sensory, but not motor, function is preserved below the neurologic level and extends through the sacral segments S4-S5
- C - Incomplete: Motor function is preserved below the neurologic level, and most key muscles below the neurologic level have muscle grade less than 3

D - Incomplete: Motor function is preserved below the neurologic level, and most key muscles below the neurologic level have muscle grade greater than or equal to 3

E - Normal: Sensory and motor functions are normal

In addition, the following terminologies have been developed around the classifications of SCI. Tetraplegia (replaced the term quadriplegia) refers to injury to the spinal cord in the cervical region which associates to the loss or impairments of motor and sensory functions in all 4 extremities. Paraplegia refers to any injury to the spinal cord in the thoracic, lumbar, or sacral segments, including the cauda equina and conus medullaris (Ditunno et al., 1994; Maynard et al., 1997).

National Spinal Cord Injury Statistical Center reports that the number of patients with iSCI has steadily increased from 45.9% in the 1970s to 55.3% in 2005 (National Spinal Cord Injury Statistical Center, 2006). One-third of patients with SCI are reported to be tetraplegic and 50% of patients with SCI have an incomplete lesion. The mean age of patients sustaining the injury is 33 years old, and most of them were males with the sex distribution between men and women of 3.8:1. In Asia, the incidence of SCI was 23.9 per million per year (1995-2005) (Wyndaele, 2006). Fortunately, the ten-year survival rate of spinal cord injured patients is 86.3% of normal (Subbarao, 1991). Moreover, with advances in technology and therapeutic strategies, ambulatory after SCI is becoming more common everyday (Lapointe et al., 2001; Kim et al., 2004). However, only a few of them can become functional walkers (Amatachaya et al., 2010).

2. Clinical factors influencing ambulatory potential

In patients with SCI, the quality and method of ambulation adopted vary from one patient to another because of by many factors such as upper and lower extremity strengths, ability of balance control, severity of paralysis, spasticity, age, and pain (Subbarao, 1991; Scivoletto et al., 2008; Water et al., 1989). Details of each factor are as follows;

Muscle strength

Many studies suggested that muscle strength is an important factor influencing levels of functional independence and walking of patients with SCI (Curt and Dietz, 1997; Eriksrud and Bohannon, 2003; Scivoletto et al., 2008; Waters et al., 1994). Early recovery of muscle strength has been identified as a predictor of ambulatory capacity. Waters et al. (1994) reported that lower extremity motor recovery 1 month post-injury was a good predictor of whether an individual would become a community ambulator at the 1-year follow-up. Moreover, Crozier et al. (1992) found that individuals who recovered good muscle strength in the less affected quadriceps (greater than grade 3) in 2 months after SCI had an excellent prognosis for ambulation. Some studies indicated that the strength of lower extremity muscles correlated with gait speed and ambulatory capacity in people with both acute and chronic SCL (Curt and Dietz, 1997; Waters et al., 1994). Lower extremity muscle correlates with strength and gait speed, walking endurance, and ability to ambulate in a community (Kim et al., 2004). However, Wirz et al. (2006) reported that muscle strength did not relate to walking ability. This difference may be due to the method of muscle strength assessment that likely assesses individual muscles in a static lying or sitting position (Maynard et al., 1997). Such method does not account for other individual constraints such as muscle tone, balance, sensation and psychological status of individuals (Lusardi et al., 2003). Results of the test that reporting as a graded level also have low sensitivity for score above the grade 3/5 level (Eriksrud and Bohannon, 2003). Kim et al (2004) indicated that important determinants of functional walking performance are hip extensors, hip abductors, and knee extensor muscles. Among these, only quadriceps muscles include in the key muscles as proposed by the ASIA protocol.

Balance and postural control

Balance and postural control is important for ambulation capacity in ambulatory patients with iSCI (Behrman and Harkema, 2000; van Hedel, 2009). Saraf et al. (2010) suggest that community walkers demonstrated significantly greater balance, balance confidence and gait efficiency (i.e., lower oxygen cost) compared to household walkers (Saraf et al., 2010). In addition, postural impairments after SCI could lead the patients to have loss of balance and fall (Leroux et al., 2006).

Severity of injury and residual motor and sensory function

Krawetz and Nance (1996) suggested that the level of injury is factor affecting the quality of gait in functional ambulators after SCI (Krawetz and nance, 1996).

Lesions below T10 are associated with a higher residual functional level and a greater ability to walk. Associated injuries, a recent surgical procedure, and medical conditions affect a person's ambulatory potential (Subbarao, 1991). The motor scores of the ASIA protocol are best related to the recovery of functional ambulatory capacity in acute paraplegic and tetraplegia patients (Curt and Dietz, 1997). Furthermore, a return of the early somatosensory evoked potentials (SSEP) components in the initial stage of SC1 can precede a clinically detectable improvement of motor and sensory functions (Rowed et al., 1978).

Spasticity

Spasticity is often experienced by individuals with SCI (Adams and Hicks, 2005). It restricts activities of daily living, inhibiting effective walking and self-care (Kirshblum, 1999; Burchiel and Hsu, 2001). In patients with stroke and other neurologic pathologies it has been shown that treating spasticity is associated with an amelioration of walking performances (Ofluoglu et al., 2003). More recent studies have demonstrated the negative relationship between spasticity and walking ability in patients with neurologic lesions of various etiologies (Hsu et al., 2003; Lebiedowska et al., 2004). However, on an empirical base it has been conjectured that spasticity could be an advantage in patients with a lower limb strength deficit because it might increase the support function (Scivoletto et al., 2008).

Age

Chronologic age by itself neither contributes a positive nor negative impact on walking. However, advancing age likely induces the deteriorations of systems involving with walking such as cardiopulmonary neuromuscular and somatosensary systems (Subbarao, 1991). Thus several evidences reported that walking recovery in patients with iSCI depends on age, where the recovery is more possible in young patients (Burns et al., 1997; Penrod et al., 1999 and Scivoletto et al., 2008). Penrod et al. (1990) has suggested a strong correlation of future ambulatory status with age in central spinal cord injured patients, noting that over age 50 the prognosis to become ambulatory was significantly worse than for patients less than 50 years old (Penrod et al., 1990).

Moreover, there are many factors influencing levels of ambulatory potential. These factors include the presence of contractures, patient's level of conditioning, motivation, pain, and medical conditions (Subbarao, 1991; Scivoletto et al., 2008; Water et al., 1989). These factors hinder walking ability of the patients. Thus their ambulatory potentials are limited within a certain location, in an abnormal manner, and requirements of an assistive device (Lapointe at al., 2001; Melis et al., 1999; Scivoletto et al., 2008).

3. Ambulatory assistive devices

Ambulatory assistive devices such as walkers, crutches and canes help to promote stability while walking by increased base of support (BOS). The devices also can assist in force production by the upper extremities to compensate for weakness of lower extremity muscles; thus can decrease load onto the lower extremities (Bateni and Maki, 2005; Melis et al., 1999) As a result, the assistive devices are commonly prescribed to persons for a variety of reasons including to decrease excessive weight bearing on the lower extremities, correct body imbalance, reduce muscle fatigue, or relieved pain secondary to loading of damaged structures (Bennett et al., 1979). Hence, selection of an appropriate ambulatory assistive device should depend on the results of an objective assessment regarding person's functional requirements and physical capabilities (Melis et al., 1999). Bateni and Maki (2005) suggest that canes and walkers can improve balance and mobility of older adults and people with other clinical conditions, including SCI patients. Melis et al. (1999) studied influence of walkers, crutches and canes on assisted-gait following iSCI. They found that ambulatory devices affected posture and walking speed while fulfilling various assistive functions during locomotion. The details of each walking device are as follows;

Walkers

A walker provides the greatest vertical support up to 100 percent of body weight (Bateni and Maki, 2005). It improves stability in patients with lower extremity weakness or poor balance, facilitates mobility by increasing the patient’s base of support and supporting the patient’s body weight. However, a walker is difficult to maneuver includes poor posture and reduces arm swing (Faruqui and Jaeblon, 2010). It requires greater attentional demands than canes, and is difficult to navigate through stairs and resulted in slow speed (Bateni and Maki, 2005).

Crutches

Crutches are helpful for patients who need to use their arms for weight bearing and propulsion. However, crutches require substantial energy expenditure, and arm and shoulder strength, thus the device is inappropriate for frail older adults (Faruqui and Jaeblon, 2010). One crutch can provide up to 80 percents of body weight, and two crutches can provide up to 100 percents of the subject's body weight, granted lateral stability, and provides restraint in the antero-posterior direction. Comparing to walking with walkers, crutch users walked faster with a greater step length and cadence, and had a more upright posture (Bateni and Maki, 2005).

Cane

Canes can help to redistribute weight from a weak or painful lower extremity, and improve stability by increasing the base of support. It provides tactile information about the ground to improve balance, offers restraining and propulsive assistance, some lateral stability, and the least amount of vertical support (Bateni and Maki, 2005). Canes also associate with the improvement of self-reported functional ability and confidence. Although several types of canes are available, there is little evidence supporting the use of one type of cane over another (Alexander, 1996).

Thus, rehabilitation professionals are advised to match device characteristics to user needs when prescribing walking aids (Melis et al., 1999). Van Hedel et al. (2005) suggest that assessment of the requirement of walking device is an important outcome measure in rehabilitation. Furthermore, Haisma (2008) indicates that it is important to investigate opportunities to optimize walking function following SCI.

4. Walking capacity assessment following SCI

Persons with iSCI ranked walking ability as one of the most important functions for recovery. Normally, ambulation is one of the most obvious functional skills that can be observed and measured by clinicians. The ability can be measured using various components such as speed, distance, time, use of assistive devices, amount of physical assistance, physiologic demand, kinematic assessment, and so forth. Each of these may be measured singularly or in combination (Read et al., 2008). Van Hedel et al. (2008) indicated that a proper assessment tool should be able to detect a small functional change in order to be capable to demonstrate possible positive/negative treatment effects.

In general methods of clinical evaluation can be done using either qualitative or quantitative assessments (van Iersel et al., 2008). Qualitative assessments through observation methods are widely applied as a screening tool. However, the result is subjective and highly dependent on experience the evaluators (Mancini and Horak, 2010). In addition, the decisions about clinical relevant changes can be difficult when time intervals between visits are long or with changes in the assessors (van Iersel et al., 2008). Quantitative measures are more objective and easier to be standardized, thus results from the test can be compared among the testers and the test intervals (van Iersel et al., 2008; Mancini and Horak, 2010). As a result, quantitative functional assessments are more preferable to use as a screen tool in general clinical and community settings (Lusardi et al., 2003; van Iersel et al., 2008). The quantitative assessment relating to walking capacity can be executed using continuous data such as 10MWT, 6MWT, and TUGT, and ordinal scales such as FIM_L scores, the Spinal Cord Independence Measure (SCIM), and the WISCI. Whitney et al (2005) reported that the requirement of walking related to LEMS, ability of walking, and balance control. These abilities can objectively be measured using various methods including;

The lower extremity muscle strength (LEMS)

In the SCI population, the use of lower extremity motor scores (LEMS) have been advocated to use as an indicator of walking function. Some studies conversely report that the increase in LEMS does not always associate with the improvement of walking function (Scivoletto et al., 2008; Wirz et al., 2006). This contradiction may be due to the evaluation of LEMS is mostly applied using the method of manual muscle testing (MMT) for the individual muscles of the lower extremities. The method is rather subjective and performs mostly in lying position (Maynard et al., 1997). The result has low sensitivity for score above the grade 3/5 level (Eriksrud and Bohannon, 2003). Moreover, the key muscles of the lower extremities as designated by the ASIA protocol do not include the important determinants of functional walking performance such as hip extensors and hip abductors muscles (Kim et al., 2004). The method neither accounts for other contributors of functional outcomes such as the coactivation of muscle groups, balance, sensation and psychological status of the individuals (Lusardi et al., 2003).

Csuka and McCarty (1985) firstly described the application of the sit-to-stand test (STS) to measure lower-extremity strength (force-generating capacity of muscles). The task of rising from a chair is a common movement of daily activities. It is a crucial factor for levels of independence of many individuals (Whitney et al., 2005). Ability to perform STS is mostly consistent to lower-extremity muscle force (Eriksrud and Bohannon, 2003). The task is mechanically demand and requires adequate torques to be developed at each joint during spatial and temporal motion of the body segments are coordinated (Bahrami et al., 2000). Thus, apart from muscle strength, the task is also highly correlated to sensation, balance, speed, and psychological status of individuals (Whitney et al., 2005). Later, the STS are now commonly used to assess lower extremity strength and balance (Whitney et al. 2005). All subjects begin by sitting on the chair (Lipsitz et al., 1991) use of the arms during the STS movement was not allowed (Janssen et al., 2002). Subjects sitting with their back against the chair with their feet flat on the floor. The chair for this tests their suitable height with armrest (Whitney et al., 2005). The examiner provided the following instructions according to the standardized laboratory protocol: “I want you to stand up and sit down 5 times as quickly as you can when I say ‘Go’ ” (Whitney et al., 2005). Timing begins when the examiner said “Go” and stops when the subject’s buttocks touch the chair on the fifth repetition. The investigator instructs the subject to stand up fully between repetitions of the test. Subjects are instructed not to touch the back of the chair during each repetition. Subjects are allowed to place their feet comfortably under them during testing (Whitney et al., 2005).

The balance and postural control assessment

Impairments of balance control limit ability of the patients to walk independently at an optimal speed and distance, and compel the patients to use a walking device (Behrman and Harkema, 2000). Control of balance is complex and involves maintaining postures, facilitating movement, and recovering equilibrium. Balance control consists of controlling the body center of mass over its limits of stability. Clinical balance assessment can help to assess fall risk or determine the underlying reasons for balance disorders (Mancini and Horak, 2010).

The TUGT is a test of balance that is commonly used to examine functional mobility in community-dwelling, frail older adults (Shumway-Cook et al., 2000). It was modified from the get up and go test by introducing a timed component (Podsiadlo and Richardson 1991). The test contains a more complex task rather than 'just' walking, which might better reflect daily life activities. However, as it combines several important tasks in one test, the scores reflect the whole composite of standing up, walking, turning and sitting down. Thus it might decrease the sensitivity of the result. As a result, several studies suggested that it might be more accurate to test each phase separately i.e. testing the sit-to-stand-to-sit test using the FTSST, or testing walking using the 10MWT (Bohannon 1995; Csuka and McCarty 1985; Newcomer et al. 1993; van Hedel et al. 2008). The test has been proved to be a valuable tool to assess balance control during walking in subjects with SCI (Scivoletto et al., 2008). It concurrent validity of is good as it shows a strong correlation with the WISCI II (ρ = -0.76), the 6MWT (ρ = -0.88) and the 10MWT (r = 0.89) (van Hedel et al., 2005). The test also has high reliability (r>0.97), but, in a repetitive test, SCI subjects demonstrate better performance than the first one, even though testing by the same rater (van Hedel et al., 2005).

The walking speed assessment

Walking speed is considered as a surrogate for the overall quality of gait (and motor function) (Dobkin, 2006). However, gait speed is difficult to interpret. What is a meaningful gait speed for daily life and which increment in speed can be considered relevant? Gait speed has not been correlated with disability scales in SCI. It is therefore difficult to determine its relevance for daily life (van Hedel et al., 2008).

The 10MWT has been used for gait assessment in stroke, Parkinson disease (PD), and other neurological movement disorders. More recently the test has been successfully utilized in the SCI population. SCI alters gait mechanism, strength, and proprioception that have a direct effect on the speed of walking. Results of the test inform functional capacity rather than physical disability (Jackson et al. 2008).

Van Hedel et al (2005) investigated the tntra- and inter-rater reliability of the 10MWT in the SCI population. The test shows excellent inter-and intra-rater reliability (r = .974, P < 0.001 and r = .983, P < 0.001 respectively) (van Hedel et al. 2005). It also demonstrated high reliability in other populations such as stroke (test retest/ICC.87–.88) (Collen et al. 1990), PD (test retest reliability: ICC = .87) (Schenkman et al. 1997), and other neurological conditions (inter-rater reliability: r =.93, intra-rater: r = .990, and test-retest r = .89 – .90) (Hornby et al. 2005; Rossier and Wade, 2001). Inter-rater reliability in patients with SCI is better than intra-rater reliability (van Hedel et al. 2005).Moreover, the 10MWT correlated well with WISCI II in patients with AIS D after initial injury and at 3 months (van Hedel et al. 2006). However, the 10MWT shows better sensitivity to detect changes in locomotion than the WISCI II particularly in subjects who have less impairment due to the ceiling effect of the WISCI II (van Hedel et al. 2006). It also showed more sensitivity in patients with greater than 90% recovery of lower extremity motor score (LEMS) at 6 and 12-months post injury (AIS D) (van Hedel et al. 2006). Thus it is a good clinical utility and useful in clinical practice (Rossier and Wade, 2001; van Hedel et al. 2005).

However, van Hedel et al (2005) reported that test repeatability was dependent on the effort and performance of the patient. Bias, may also confound the reliability of this test. Age-referenced values may need to interpret data as age negatively affects walking speed (van Hedel et al. 2005). In addition, on sequential evaluations, the subject may learn the test which may alter their performance (Steffen et al. 2002). Lastly, in patients with poor walking ability, sequential tests demonstrated poor reliability due to the increment of variability in recorded values (van Hedel et al. 2005).

The researcher believes that the assessments involving with the task of walking such as FTSST, 10MWT and TUGT can indicate level of walking ability and requirement of walking devices. However, no evidence confirms this assumption. Thus this study compare results of these tests in subjects with iSCI who walking with and without walking devices. In addition, the study will also determine the correlation of these tests with walking ability.