CHAPTER II

LITERATURE REVIEW

2.1 Introduction

AH is one of the stabilizing exercise techniques for the lumbar spine that has been shown to be effective in treatment of patients with LBP (Goldby et al., 2006; Hides et al., 2001; O'Sullivan et al., 1997; Rasmussen-Barr et al., 2003; Shaughnessy and Caulfield, 2004). It is the prerequisite technique that needs to be achieved before performing other spinal stabilization exercises (Norris, 1999; O'Sullivan, 2000; Richardson and Jull, 1995). In order to promote an individual's capacity to master all the essential requirements for executing the AH, various starting positions for AH have been proposed. Four initial positions have been recommended for AH. These are crook lying, prone lying, four-point kneeling, and wall support standing positions (Norris, 1999; O'Sullivan, 2000; Richardson and Jull, 1995).

This chapter describes the concept of spinal stability, spinal instability and LBP, spinal stabilization exercises, effects of various starting positions during AH, and measurement of muscle activity.

2.2 Concept of spinal stability

The spinal stabilizing system was conceptualized by Panjabi (1992a). This concept has been widely accepted as a concept that can explain the mechanism by which the spine uses for providing its general and segmental stability (Akuthota and Nadler, 2004; Norris, 1995; Richardson and Jull, 1995). The system consists of three subsystems that always work together to provide stability to the spine; these are neural control subsystem, passive subsystem, and active subsystem (Figure 2.1). Deficit in one subsystem will influence the function of the whole system. The first subsystem is the neural control subsystem that co-ordinates muscle response. It receives feedback information from mechanoreceptors embedded within the other two subsystems which is used to activate the related muscles at the right time by the right amplitude (Panjabi, 1992a, 2006). The second subsystem is the passive subsystem which includes the vertebrae, intervertebral discs, zygapophyseal joints, spinal ligaments, and joint capsules. These structures function to resist any changes in their position and its length and to provide stability of the spine under static condition and towards the end of range of motion. The third subsystem is the active subsystem which includes the muscles and tendons surrounding the spinal column. These structures provide dynamic stability under dynamic condition.

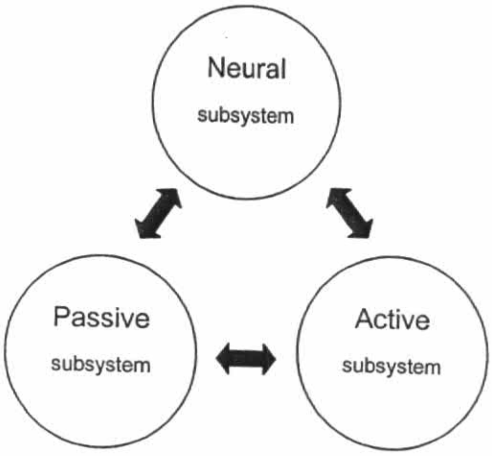

Figure 2.1 The spinal stabilizing system (modified from Panjabi, 1992a).

For better understanding of the spinal stability, Panjabi (1992b) integrated the spinal stabilizing system into the concept of load-displacement curve (Figure 2.2). There are four terms concerned with the load-displacement curve (Panjabi, 1992b). **Range of motion** is a total range of physiological intervertebral motion that is divided into elastic zone and neutral zone. **Elastic zone** is the range in which the intervertebral motion occurs against resistance provided either from the passive or the active subsystem. It is the zone of high stability. **Neutral zone** is the range in which the intervertebral motion occurs with minimal resistance provided either from the passive or active subsystem. It is the zone of low stability and high flexibility. It is the zone in which the **neutral position** lies. In this position, the spinal column is positioned in the posture of minimal stress and can be maintained with minimal muscular effort. Due to the characteristic of low stability and high flexibility of the neutral zone, it is hypothesized that an increase in neutral zone would lead to segmental instability of the spine (Panjabi, 1992b, 2003). The change in range of motion, on the other hand, is less sensitive than the change in neutral zone. *In vitro* studies showed a correlation between spinal instability and an increased in neutral zone after injury to spinal ligaments and/or zygapophyseal joints (Gay et al., 2006; Panjabi et al., 1989). The increase in range of motion, however, was less significant. It is therefore recommended that the neutral zone should be decreased in order to decrease segmental instability. One method that is widely accepted as a mean to achieve this aim is to increase the role of the active subsystem (Akuthota and Nadler, 2004; Hodges, 2003; Suni et al., 2006).

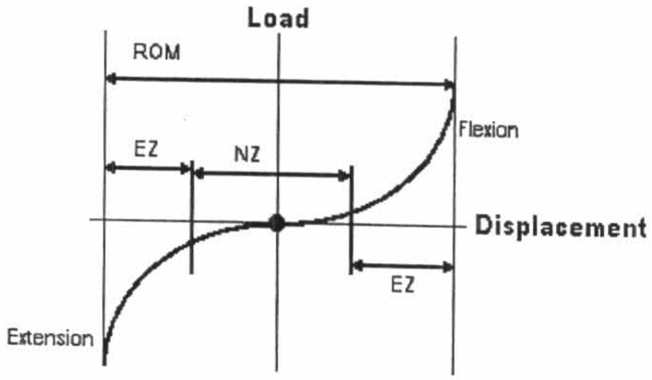

Figure 2.2 Load–displacement curve (modified from Panjabi, 2003).
ROM = Range of motion, EZ = Elastic zone, and NZ = Neutral zone.

Although all muscles surrounding the lumbar spine can contribute to spinal stabilization, some muscles play a specific role as stabilizers (Bergmark, 1989). As a result, the active subsystem is considered to consist of two muscle groups - i.e. a local and a global muscle groups (Bergmark, 1989). The local muscles have primary role in providing segmental stability to the spinal column and controlling curvature of the lumbar spine. These muscles are deep spinal muscles that have their origin and insertion at the lumbar spine. These muscles are TrA, lumbar multifidus (deep fibers), IO (lower fibers) quadratus lumborum (medial fibers), psoas major, diaphragm, and pelvic floor muscles (Akuthota and Nadler, 2004; Bergmark, 1989; Ebenbichler et al., 2001; Jemmett et al., 2004; Kiefer et al., 1998; Panjabi et al., 1989; Richardson et al., 2004). Their activities commonly occur prior to movement of trunk and limb (Comerford and Mottram, 2001). Regarding the global muscles, these muscles have primary role in producing motion of the spinal column. They are superficial muscles that do not attach directly to the lumbar vertebrae. These muscles are RA, EO, IO (upper and middle fibers), lumbar multifidus (superficial fibers), quadratus lumborum (lateral fibers), and erector spinae muscles (Akuthota and Nadler, 2004; Bergmark, 1989; Ebenbichler et al., 2001; Kiefer et al., 1998; Panjabi et al., 1989; Richardson et al., 2004). They do not provide segmental stability to the spine but they tend to provide general stability under high load situation (Comerford and Mottram, 2001).

The stabilization role of the local muscles has been proposed to relate to their attachments to the thoracolumbar fascia (Barker et al., 2006; Cresswell et al., 1994; Hodges et al., 2003a; Iscoe, 1998; Richardson et al., 2002). Their contraction would therefore increase tension in the thoracolumbar fascia and produce extensor torque. Together with the arrangement of the local muscles, which encloses the abdominal cavity (Figure 2.3), the contraction of these muscles would cause an increase in intra-abdominal pressure (Cresswell et al., 1994; Hodges et al., 2003a; Iscoe, 1998; Richardson et al., 2002). The abdominal cavity becomes a rigid cavity that resists deformation in all directions (Cholewicki et al., 1999; Hodges et al., 2004, 2005). The lumbar spine which locates posterior to the abdominal cavity would therefore be protected from any deformation during movement. This means that the lumbar spine is stable. Although several local muscles are responsible for this function, the local muscle mostly mentioned in the literature is TrA. This might be due to the finding that the TrA always co-activates together with the other local muscles in normal condition (Hodges et al., 2003a; Neumann and Gill, 2002). Thus, it is assumed that all local muscles have similar characteristics to those of the TrA.

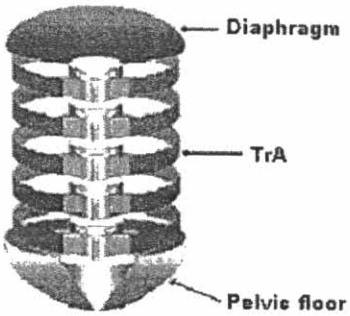

Figure 2.3 Increasing of intra-abdominal pressure by co-contraction of diaphragm, pelvic floor, and transversus abdominis (TrA) (modified from Hodges, 1999).

Recent studies have shown that local and global muscles are controlled independently. Local muscles are activated before prime mover while global muscles are activated after prime mover. TrA, IO, and lumbar multifidus (deep fibers) were found to pre-activate prior to prime mover, RA, and EO in various activities. This is to prepare the spine for perturbation from the change in body alignment during movement (Richardson et al., 2004). This is considered to be 'feedforward' and is pre-planned by the central nervous system (Richardson et al., 2004). The responses of the global muscles, in contrary, are considered to be 'feedback' as they occur in reaction to the change in body alignment (Richardson et al., 2004).

The early onset of the local muscles occurs in regardless of the direction of force that induces spinal movement (Hodges and Richardson, 1996, 1997b; Marshall and Murphy, 2003; Moseley et al., 2002). One study compared electromyography (EMG) activity of trunk muscles in healthy to LBP (Hodges and Richardson, 1996). The fine-wire EMG activity was collected from TrA, IO (middle fibers), EO, lumbar multifidus (superficial fiber), RA, and deltoid (anterior, middle, and posterior fibers). Participants were instructed to stand and move their shoulder as fast as possible in flexion, abduction, and extension. This aimed to initiate perturbation to the spine and its stability. The results showed that TrA always activated prior to deltoid in all three shoulder movements. IO (middle fibers) activated together with TrA prior to deltoid only in shoulder abduction. Later study by surface EMG found that TrA/IO was always the first muscle activated in all shoulder movements (Marshall and Murphy, 2003). With lower limb movement, similar results to those demonstrated with upper limb movement were reported. TrA and IO (middle fibers) always activated prior to hip flexors, extensors, and abductors (Hodges and Richardson, 1997a). For lumbar multifidus, the deep fibers exhibited early activation before the deltoid while the superficial fibers showed delayed activation (Moseley et al., 2002).

The pattern of early onset of local muscles and delayed activation of global muscles was proposed to occur even when an individual was unaware of the direction of perturbation or was given an incorrect preparatory information (Hodges, 2001). However, this pattern was not observed with slow limb movement. It was associated only with fast and natural limb movements. This might be because the slow movement induced relatively less acceleration and force in comparison to the fast and natural movements (Hodges and Richardson, 1999). Subsequently, the stability of the spine was minimally disturbed and required minimal contribution from local muscles.

The other difference between local and global muscles is their contraction duration. As long as the perturbation exists, the local muscles maintain their contraction. This is so called 'tonic activation' (Hodges and Gandevia, 2000; Liebenson, 1997; Moseley et al., 2002). Conversely, the global muscles activated sporadically according to the direction of perturbation. This is so called 'phasic activation' (Liebenson, 1997).

In summary, three subsystems of the spinal stabilizing system have an important role in providing spinal stability. Co-ordination of the neural control and the active subsystems are important. Both local and global muscles have an important role to provide spinal stability. However, local muscles have a major role in controlling segmental stability of the lumbar spine. The specific characteristics of local muscles are that they are deep muscles, are pre-activated prior to prime mover in all directions, and respond in a tonic manner.

2.3 Spinal instability and LBP

Based on the concept of the spinal stability presented above, the three subsystems must work in harmony to provide mechanical stability needed for the lumbar spine. The dysfunction in any subsystems would therefore cause spinal instability and LBP. This section describes the dysfunctions of local and global muscles that have been found in association with LBP.

For local muscles, they lose their ability to activate prior to movement in various directions. A significantly delayed activation of TrA was found in association with all directions of limb movements in people with chronic LBP (Hodges and Richardson, 1996). Patients with LBP failed to recruit TrA and IO (middle fibers) in advance of limb movement both at fast and natural speeds (Hodges and Richardson, 1999). Greater delayed activation of TrA was found to occur when the patients were unaware of the direction of perturbation or was given an incorrect preparatory information (Hodges, 2001). This delayed activation does not only happen in patients with chronic LBP but also happen in acute LBP. A study, which experimentally induced LBP by injecting hypertonic saline into the lateral portion of lumbar longissimus, found consistently reduction in amplitude or delayed onset of TrA EMG activity during shoulder flexion (Hodges et al., 2003b). A similar delayed activation of TrA/IO was also reported in a study that experimentally induced LBP by applying noxious cutaneous electric stimulation to both posterior superior iliac spines (PSIS) (Moseley and Hodges, 2005). This suggests that the control mechanism of the muscles has changed from feedforward mechanism to feedback mechanism. Moreover, the local muscles has changed from tonic activation to phasic activation (Hodges et al., 2003b).

Imaging studies have shown changes in the size and appearance of local muscles in LBP. The local muscles, both TrA and lumbar multifidus showed atrophy in LBP patients. During an exercise that focused on local muscles, the TrA thickness in individuals with LBP or with a history of LBP was shown to increase relatively less than those without LBP (Harrison and Hodgson, 2001). This is supported by the finding of a significantly smaller increase in TrA thickness in subjects with LBP compared with control during lower limb movements (Ferreira et al., 2004). This reflects that the function of TrA in those with LBP may be impaired. A significant decrease in lumbar multifidus cross sectional area was also reported in patients with chronic LBP (Barker et al., 2004; Danneels et al., 2000; Fryer et al., 2004). The atrophy was shown both in the slow and fast twitch fibers (Yoshihara et al., 2001). The muscle fibers were replaced with adipose or connective tissue. It was revealed that the lumbar multifidus of chronic LBP patients contained greater fat infiltration than healthy participants (Kjaer et al., 2007; Mengiardi et al., 2006). The muscle fibers themselves also showed transformation from slow twitch to fast twitch fibers (MacDonald et al., 2006; Mannion, 1999; Mannion et al., 2000).

For global muscles, their muscle activity was augmented in LBP (Dieën et al., 2003; Moseley and Hodges, 2005; Zedka et al., 1999). Increased EMG activity of EO was reported when applying noxious cutaneous electric stimulation at both PSIS (Moseley and Hodges, 2005). Increased EMG activity of erector spinae was found after injecting hypertonic saline into lumbar longissimus (Zedka et al., 1999). The increased activity of global muscles is hypothesized to be a mechanism for adaptation to pain by trying to splint the trunk from all aggravating movements.

All recent studies showed evidence to support concept of spinal stabilizing system. They found impairment in the local muscles together with their control in patients with LBP. Therefore, a number of studies have proposed therapeutic exercises with the aim to restore the stabilization role of the local muscles in order to prevent spinal injury and LBP.

2.4 Spinal stabilization exercises

A number of exercises have been proposed for increasing the stability to the spine. In general, these spinal stabilization exercises can be divided into two groups. They are the general and the specific exercises. The maneuvers for performing both exercises are similar in that they could share the same starting position and body movement. The only difference is that the general stabilization exercises do not particularly focus on the local muscles while the specific stabilization exercises do.

For the general stabilization exercises, several muscles are activated simultaneously. These exercises include pelvic tilt, bridging, and limb movement during quadruped exercise, etc. The exercises can be done with or without additional equipment such as a physioball that induces unstable surface for the trunk or limb to stay on. As the participants receive no instruction on the contraction of the local muscles prior to the contraction of the global muscles, the greater EMG activity of global muscles was noted. For pelvic tilt in crook lying position, the participants were instructed to contract the lower part of abdominal muscles to rotate the pelvis posteriorly so that the lumbar spine became flat against the plinth. The pelvic tilt was performed in crook lying with both hips and knees flexed at 90 degrees with and without support under both legs. Lower EMG activity of global muscles such as the RA and EO was demonstrated during crook lying with support in comparison with the EMG activity produced during crook lying without support (Drysdale et al., 2004). Bridging exercise was found to activate erector spinae and lumbar multifidus (superficial fibers) more than IO and EO (Stevens et al., 2006). In quadruped exercise with arm and opposite leg movement, high EMG activity was found in erector spinae and EO while minimal EMG activity was found in TrA/IO (Marshall et al., 2005). The RA showed very low-level activity in quadruped exercise (ranged from approximate 3-5 percent of MVC) (Marshall et al., 2005, Souza et al., 2001). Similar EMG activity was noted when performing the quadruped exercise with a physioball (Marshall et al., 2005, Souza et al., 2001). These findings suggest that the general stabilization exercises tend to activate global muscles more than local muscles.

The results of general stabilization exercises show significant reduction in pain and functional disability. A randomized controlled trial in middle-aged working men with recurrent LBP found a statistically significant reduction in pain intensity after a 12 months of general stabilization exercises in comparison to those who did not exercise (*p* = 0.028) (Suni et al., 2006). The program of exercises consisted of balance with a stick on one leg exercises, abdominal curl up with slight rotation, squat with a stick standing on one and two legs, horizontal side-support, stretching hip flexors, balance and trunk muscle exercises on hands and knees, stretching knee flexors, upper body rotation with a rubber band, and upper body rotation while side-lying. After 12 months, the participants who were in the stabilization exercise group showed a change in visual analog scale (0-100 millimeters) from 9.9 to 5.5 millimeters while it changed from 11.8 to 10.2 millimeters in the control group. The functional disability was also found to decrease after four weeks of general stabilization exercise program with upper body extension, alternate arm and leg lift, alternate arm and leg extension on all fours, diagonal curl-up, and curl-up (Sung, 2003). The decrease in functional disability was also reported with different program of general stabilization exercises, which consisted of bracing, quadruped with bracing, and side support in various positions (Hicks et al., 2005). Among 54 participants who participated in the eight weeks of stabilization exercise program, 18 and 21 participants were categorized as succeeded and improved with treatment, respectively. Fifteen participants were categorized as failure with treatment. Participants who succeeded had the Oswestry Disability Index score changed 50 percent or over while the score changed less than six points in those who failed.

For the specific stabilization exercises, the local muscles were targeted to emphasize. This fundamental exercise is known as 'AH'. During AH, participants were instructed to gently pulled the navel in and up by not allowing any movement at the spine, rib, and pelvis and hold this position for 10-60 seconds (Norris, 1995; O'Sullivan, 2000; Richardson and Jull, 1995). The exercises require an individual to master the skill of isolated contraction of local muscles with little or no activity of global muscles before integrating this skill into functional activities (O'Sullivan, 2000; Richardson and Jull, 1995). It is recommended that the local muscles must be activated within the range of low load activity of approximately 25 percent of MVC in order to be beneficial for the specific stabilization exercises (Richardson and Jull, 1995). Study in healthy participants confirmed that TrA and IO were preferentially recruited during AH (Barnett and Gilleard, 2005). Ultrasound imaging technique showed greater change in muscle thickness in TrA than in EO and IO approximately 50 percent (Critchley, 2002). Less EMG activity of RA and EO was produced during AH in comparison to during pelvic tilt (Drysdale et al., 2004).

The results of specific stabilization exercises have been shown to be more effective than the general stabilization exercises in that they not only show significant reduction in pain and functional disability but they also help decrease the recurrent rate of LBP. It was shown in patients with acute, first-episode LBP that they experienced fewer recurrences of nonspecific LBP than the controls after practicing specific stabilization exercises for four weeks (Hides et al., 2001). At one year after the treatment, the recurrence of the patients in the exercise group was 30 percent while it was 84 percent in the control group. After two to three years, the recurrences were 35 percent for the specific stabilization exercise group and 75 percent for the control group. In patients with sub-acute and chronic nonspecific LBP, the specific stabilization exercises also seem to be effective in terms of pain, general health, and functional disability levels. These variables were significantly improved after a 6-week AH exercise on a weekly basis ($p < 0.05$) and were maintained at the 3- and 12-month follow-ups (Rasmussen-Barr et al., 2003). The median of pain intensity changed from 33 centimeters at the beginning of the exercise to 20, 14, and 13 centimeters at 6-week of the exercise, 3-, and 12-month follow-ups, respectively. The similar changes were also found in the median of the general health from 35 to 21, 20, and 18, respectively; as well as in the median Oswestry Disability Index from 18 to 9, 6, and 8, respectively. In addition to the effectiveness of the specific stabilization exercises in regard to pain, general health, and functional disability level; it was shown that the ten weeks of specific stabilization exercises could improve the patients' quality of life (Goldby et al., 2006; Shaughnessy and Caulfield, 2004).

For chronic LBP with radiologic diagnosis of spondylolysis or spondylolisthesis, the specific stabilization exercises also appeared to be more effective than the general stabilization exercises. After 10-week specific stabilization exercises involving the specific training of local muscles, a statistically significant reduction in pain intensity and functional disability levels were demonstrated ($p < 0.0001$) (O'Sullivan et al., 1997). The changes in pain intensity and Oswestry Disability Index from the beginning to the end of the 10-week exercise program were 59 to 19 and 29 to 15, respectively. These reductions were maintained at a 30-month follow-up.

In conclusion, it seems that the specific stabilization exercises are more effective than the general stabilization exercises. AH and other techniques of the stabilization exercises are not only effective at reducing pain, functional disability, and recurrence of LBP but they also help improve general health and quality of life.

2.5 Effects of various starting positions during AH

Trying to practice AH in different body postures and starting positions is one of the strategies recommended for enhancing patients perception of local muscle contraction (Richardson et al., 2004). As a result a number of starting positions have been suggested, for instance, crook lying, prone lying, side-lying, four-point kneeling, and wall support standing (Norris, 1999; O'Sullivan, 2000; Richardson et al., 2004). However, there is limited evidence to support the selection of these starting positions for performing the AH. This section presents the starting positions described in the literature.

In crook lying position, a person should lie on his/her back with knees flexed at 90 degrees (Drysdale et al., 2004) or hips flexed at 45-70 degrees (Allison et al., 1998; Hubley-Kozey and Vezina, 2002; Urquhart et al., 2005; Vezina and Hubley-Kozey, 2000). This position has been suggested as an appropriate position for facilitating the contraction of TrA as it is the non-weight-bearing position which takes load off the spine

(O'Sullivan, 2000; Richardson et al., 2004). The global muscles are less active because they are not required to support the body against the gravity. By having healthy participants to perform AH in crook lying, the EMG activity of RA and EO was approximately 0.05 and 0.1 percent of MVC, respectively (Drysdale et al., 2004). The other study in healthy participants showed mean percentages of MVC of RA and EO of 6.3 and 18.1 percent, respectively (Vezina and Hubley-Kozey, 2000). Raw EMG activity of RA and abdominal oblique muscles was 0.05 and 0.14 millivolts, respectively (Allison et al., 1998). Similar result was also demonstrated in LBP patients. The mean percentages of MVC of RA and EO were 5 and 13.9 percent, respectively (Hubley-Kozey and Vezina, 2002).

In prone lying position, a person should lie prone on the plinth with a small pillow placed under the ankles (Richardson and Jull, 1995). This position was suggested as a suitable position for performing AH (O'Sullivan, 2000; Richardson and Jull, 1995). It facilitates the contraction of TrA in a similar manner to crook lying (O'Sullivan, 2000; Richardson et al., 2004). It is proposed that the activity of global muscles would be reduced while the activity of local muscles would be enhanced (Richardson and Jull, 1995). A study by Beith et al (2001) found that the EMG activity of RA was almost zero and the EMG activity of EO was 9.5 percent while performing AH in prone position. Approximately 25 percent of participants could always isolate IO activity in this position. The frequencies of participants who could sometimes and never performed isolate IO activity were 15 and 60 percent, respectively.

In four-point kneeling position, the hips are positioned directly on the knees while the shoulders are directly on the wrists with a small pillow placed under the ankles (Norris, 1999; O'Sullivan, 2000; Richardson and Jull, 1995). This position was suggested as a suitable position for performing AH (Norris, 1999; O'Sullivan, 2000; Richardson and Jull, 1995). This positions also take load of the spine (O'Sullivan, 2000). TrA is sagged by the gravity and it is proposed that the stretch receptors within the muscles would be stimulated (Norris, 1999). Mean increase of 49.71 percent in TrA thickness during AH was found in previous study (Critchley, 2002). The EMG activity of RA was nearly zero while the EMG activity of EO was 8.5 percent (Beith et al., 2001). Frequencies of participants who could always, sometimes, and never isolate IO activity during AH was 55, 15, and 30 percent, respectively (Beith et al., 2001).

In side-lying position, the upper trunk and pelvis should be aligned in a straight line while the lower extremities can be flexed at both hip and knee joints for comfort and stability (Cynn et al., 2006). This position is recommended as one of several positions to train AH as it is a non-weight-bearing position which takes load of the spine (Richardson et al., 2004). Less muscle activity from global muscles could be expected. In this position, the weight of the abdominal contents might place tension on the lateral abdominal muscles such as TrA, IO, and EO. This therefore would provide a stretch stimulus to TrA activation (Richardson et al., 2004). However, the evidence to recommend this position over the others is limited. One study investigation AH with hip abduction in side-lying found increased activity of IO and decreased activity of RA, EO, and quadratus lumborum (Cynn et al., 2006). The investigation of abdominal muscle activity during AH alone in side-lying position is lacking.

In wall support standing position, the back contacts with the wall surface and both knees are extended by keeping both heels at six inches from the wall (Norris, 1999). No scientific evidence has been provided in regard to the reason why this position would be an appropriate position for performing AH. The empirical suggestion is that the therapists should try this position if the patients fail to perform AH in four-point kneeling position (Norris, 1999).

To date, there have been only two studies that compared the effectiveness of the starting positions for performing AH (Beith et al., 2001; Urquhart et al., 2005). The first study was conducted by Beith et al (2001). They compared between prone lying and four-point kneeling positions and found no statistical difference in the activity of the IO between positions. Higher IO EMG activity in prone lying than four-point kneeling was found. However, they reported that it tended to be easier to achieve isolate activation of IO in four-point kneeling position in comparison to prone lying position. The second study was carried out by Urquhart et al (2005). They compared between crook lying and prone lying positions. It was found that crook lying could encourage the TrA to work in isolation better than prone lying position. But the prone lying position in their study was modified from normal and differed from the one that has commonly been recommended to the patients. The researchers had their participants lay prone with the boxes support at xiphisternum and pubic symphysis. The abdomen did not contact with the plinth. So the prone lying position in their study looks like four-point kneeling position. The stretch stimulus on the TrA that is not present in normal prone lying position may occur in the recent study. It can be seen that the effects on the starting positions on the activity of abdominal muscles during AH are limited.

2.6 Measurement of muscle activity

There are a number of instruments used for measuring muscle activity during AH (Barnett and Gilleard, 2005; Beith et al., 2001; Cairns et al., 2000; Critchley, 2002; Cynn et al., 2006; Drysdale et al., 2004; Urquhart et al., 2005). These include a pressure biofeedback unit, ultrasound imaging, and EMG. This section reviews and discusses the advantages and disadvantages of each instrument.

2.6.1 Pressure biofeedback unit

A pressure biofeedback unit is initially developed for assessing the ability of abdominal muscles to function as spinal stabilizers while performing AH (Richardson et al., 2004). It consists of a three-chamber air-filled pressure bag connected to a pressure gauge and an inflation device. The pressure gauge has a range from 20 mmHg to 100 mmHg, with 2- mmHg intervals on the scale. It is used by placing it in the space between supporting surface and lower abdomen or lower back. Contraction of trunk muscles causes change in pressure being applied on the unit is registered as a change in muscle activity.

Although this instrument is relatively inexpensive and can be available in clinics, it has some disadvantages. The value registered on the scale is a result from more than one muscle work. The contribution of each trunk muscle to the change in muscle activity recorded is unknown. This instrument can be used for measure muscle activity only in the position that the participants' trunks contact with supporting surface.

2.6.2 Ultrasound imaging

A real time ultrasound scanner with a transducer is used to measure muscle activity by measuring the changes in muscle thickness (Ainscough-Potts et al., 2006; Critchley, 2002; Ferreira et al., 2004; Harrison and Hodgson, 2001) The greater increase in muscle thickness represents the greater muscle activity. It is considered to be a valid instrument that can provide information in regard to individual muscle activity. However, a limited number of muscles can be monitored at a time. All muscles that contribute to movement cannot be measured simultaneously. Only the muscles that are in the area of the ultrasound transducer are displayed and measured on the screen.

2.6.3 EMG

EMG is an instrument that is considered to be a gold standard instrument and is widely used for measuring muscle activity (Soderberg and Knutson 2000). Several muscles can be investigated simultaneously. Muscle activity is measured by inserting electrodes into muscle fibers or attaching electrodes on the skin over the muscles. These electrodes detect the amount of muscles activity generated by each muscle during movement. Two types of electrodes used with this instrument are fine-wire and surface electrodes. They are known as fine-wire EMG and surface EMG, respectively.

Fine-wire EMG provides information of muscle activity from muscle fibers. Each wire has 50 micrometers or less in diameter. The number of muscle fibers recorded varies depending on the amount of wires inserted into the muscle. It allows the researchers to investigate the activity of deep muscles. However, the serious complication of fine-wire EMG is the participants discomfort, pain, and muscle trauma (Hogrel, 2005).

Surface EMG provides information of muscle activity from larger area. Surface electrodes are placed on the skin over the muscles being investigated. It is recommended to be a better representative of muscle activity than fine-wire EMG (Hogrel, 2005). Due to the attachment of the electrodes on the skin surface, it is considered to be the best for assessing superficial muscles not deep muscles. However with some specific sites, some deep muscles can also be assessed with surface EMG. For abdominal muscles, recent studies have shown that the muscle activity of TrA and IO can be effectively examined with surface EMG (Marshall and Murphy, 2003; Moseley and Hodges, 2005). Similar results in abdominal muscle activity during movements have been reported from both surface and fine-wire EMG (Hodges and Richardson, 1997b; Marshall and Murphy, 2003). The surface EMG is widely accepted to be used for investigating the activity of abdominal muscles during AH and for discriminating whether an individual has any problems in controlling of spinal stability (Arokoski et al., 2001; Arokoski et al., 2004; Drysdale et al., 2004). It has advantage in that it does not produce discomfort to the participants and it is safer and easier than fine-wire EMG with high reliability (ICC = 0.90 in shoulder flexion and extension) (Hogrel, 2005; Marshall and Murphy, 2003). However, crosstalk and skinfold thickness of target area should be considered during measurement (Merletti and Parker, 2004; Neumann and Gill, 2002).

2.7 Conclusion

Specific stabilization exercises have been found to be more effective than the general stabilization exercises in treating patients with LBP. They also help decrease the recurrences of LBP in the long term. The basic exercise for the specific stabilization exercises is AH. There are many options of starting positions for AH exercise. Previous studies showed variety EMG activity in different positions during AH. However, there has been no study that compared EMG activity of abdominal muscles in four starting positions of AH. Therefore, this study examined surface EMG activity of RA, EO and TrA/IO during performing AH in crook lying, prone lying, four-point kneeling, and wall support standing positions.